Acoustic Thermometry of Ocean Climate (ATOC): Pioneer Seamount Source Installation

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ABSTRACT

The ATOC acoustic source was installed on Pioneer Seamount during October and November 1995. Three vessels were used for this work. On 5 October, M/V *McGaw* laid 3 nmi of cable at Pillar Point, California. The cable is terminated at the Pillar Point Air Force Station. On 14 October, a survey of the proposed source site on Pioneer Seamount was conducted using the U.S. Navy's Deep Submergence Vehicle *Sea Cliff* (DSV 4) deployed from M/V *Laney Chouest*. This survey determined the precise location for the source and deployed acoustic transponders for relocating the site. The source deployment using M/V *Independence* was done in four steps during 24 October to 3 November. One length of deep-stowed cable was recovered off Point Sur. The source was deployed on 28 October, and this first length of cable laid toward shore. A second piece of deep-stowed cable was recovered off San Simeon. It then was spliced to the first piece, laid to shore, and spliced to the cable at Pillar Point. Engineering test transmissions were made after deployment of the source to ensure that it was functioning correctly. The best estimate for the position of the center of the acoustic source is 37°20.5550′N, 123°26.7117′W at 938.7 m depth.

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1. INTRODUCTION

This report describes the installation of a very-low-frequency projector at Pioneer Seamount. This and another acoustic projector to be installed off Kauai will transmit sound to receivers across the Pacific. Acoustic travel times from the projectors to the receivers will be measured. The measured travel times are indicative of ocean temperature and will be used to study ocean variability and climate change. This work is part of the multi-institution Acoustic Thermometry of Ocean Climate (ATOC) project sponsored by the Advanced Projects Agency (ARPA). Institutions involved in this project include the Applied Physics Laboratory at the University of Washington (APL-UW), the Scripps Institution of Oceanography (SIO), the University of Michigan (UM), and the Massachusetts Institute of Technology (MIT).

APL-UW has overall responsibility for the installation and operation of the acoustic sources. SAIC/MariPro was contracted to do much of the work associated with the cable laying and the source deployment at Pioneer Seamount.

This document describes the installation work. Additional background information can be found in the bid specification for the installation work (Olson, 1995), the cruise and installation plan (Howe, 1995), the description of the source and instrumentation by the ATOC Instrumentation Group (1995), the report on the original cable-route survey (Seafloor Surveys International, 1993), the report discussing the relative merits of the two candidate California source sites (Howe, 1993), and the environmental impact statement (ARPA, 1995).

A chronology of the operations is given in Appendix A. Three vessels were involved over a period of 6 weeks. M/V *McGaw* picked up 3 nmi of armored cable from STC in Portland, Oregon, on 29 September and then laid it at Pillar Point, California, on 5 October. It is terminated at the Pillar Point Air Force Station. On 14 October, a survey of the proposed source site on Pioneer Seamount was conducted using a manned underwater vehicle, the Navy's Deep Submergence Vehicle *Sea Cliff* (DSV 4), deployed from M/V *Laney Chouest*. This survey determined the precise location for the source and deployed acoustic transponders for relocating the site. The source and associated electronics as well as all the cable-laying equipment were loaded on M/V *Independence* in Port Hueneme starting 20 October. A practice deployment of the source was conducted in Santa Barbara Channel in the early morning hours of 24 October. Cable recovery was done in two steps because it had been determined that the deck of the *Independence* could not support the weight of all the cable. The Point Sur cable was recovered first. It had been severely damaged by fishing gear, and it had to be recovered in two sections. Then the source was deployed on 28 October; this required 2 days because on the first attempt an electrical fault was found in the cable termination on the source package. The first (Point Sur) section of cable was laid from the source toward shore, and the end was

left with a recovery release. Then the required length was recovered from the San Simeon cable, spliced to the first section (called the sea cable), laid toward shore, and spliced to the cable (called the shore cable) coming from Pillar Point. Engineering test transmissions (a total of 12 over 4 days) were made after deployment of the source to ensure that it was functioning correctly.

At the time that this report goes to press (April 1996), the source is working as expected. Clear arrivals are being received on Navy receivers at 5 Mm range in the western Pacific and on two vertical line arrays (VLAs), one at 3 Mm range off Hawaii and one at 5 Mm range off Kiritimati (Christmas) Island.

This worked proceeded under the following permits: California Coastal Commission Permit 3-95-40, Monterey Bay National Marine Sanctuary Permit MBNMS-12-95, National Marine Fisheries Service Scientific Research Permit 968, and Air Force Memorandum of Understanding FB4610-M36.

2. SOURCE PACKAGE DESCRIPTION

The acoustic source is an Alliant Techsystems HX-554 bender-bar, barrel-stave projector roughly 7 ft high by 3 ft in diameter and weighing 5000 lb (Figure 1). It is contained in a 12-ft-high, hot-dipped galvanized steel, tripod-shaped frame (Figures 2 and 3). Total weight in air is 12,000 lb, in water about 7,500 lb. The source is isolated from the frame by shock mounts. There are three 6000-psi nitrogen gas bottles, with an acoustically actuated valve, for pressure compensation. The sea cable mates with a transmit/receive (T/R) network which connects it to either the projector or a receiver. The default position is for source operation, reflecting the higher importance of the projector relative to the receiver. A schematic of the entire electrical system is shown in Figure 4.

The receiver package contains four hydrophones, a tilt sensor, and temperature and pressure sensors, all collectively called "the receiver" here. The hydrophones are on a 100-m-long vertical line array at a nominal spacing of 33 m (Figure 5). For deployment, the VLA was coiled in a plastic bucket; after 2 days, corrosion links parted, and a 24-in syntactic foam float deployed the hydrophone array. The tilt sensor in the receiver package on the tripod transmitted its signal acoustically through the water (the frequency is proportional to the tilt) as well as electrically up the cable. The performance of the receiver grew progressively worse during the weeks following installation until it failed completely on 21 November.

All pressure cases are plated mild steel with double O-ring seals. All exposed electrical cables are protected by running them inside steel pipe or heater hose. All components have a design life in excess of 10 years. A recovery-line basket with an acoustic release (with lithium batteries good for 5 years) is mounted on one corner of the the tripod to simplify eventual recovery. Two Benthos TR6000 17-in. glass-ball acoustic transponders are mounted on the other corners. (See ATOC Instrumentation Group, 1995, for details of the entire source system.)

3. SOURCE SITE DESCRIPTION AND *SEA CLIFF* SURVEY

The ATOC source is located on the southwest tip of Pioneer Seamount, about 50 nmi west of Pillar Point, California. The precise position and site description were refined after the survey (described below) using the *Sea Cliff*. The source location will be referred to as Point Love. Site selection criteria are discussed by Howe (1993), and the initial site and cable route survey is described by Seafloor Surveys International (1993).

Figure 6 illustrates the ATOC source site on Pioneer Seamount and the cable route along the ridge of the seamount and up the continental slope and shelf to the Air Force Station at Pillar Point. Figure 7 shows the seamount and cable route in more detail. Figures 8–10 provide three different versions of the bathymetry in the vicinity of the source site. The data in Figure 8 were obtained with a 9-kHz sidescan sonar (Sys09) towed 100 m behind and below the survey ship; the position of the ship was determined with Starfix accurate to within several meters, and the position of the sonar relative to the ship with an ultra-short-baseline acoustic tracking system. Subsequent data collected by the SeaBeam system on M/V *Laney Chouest* (Figure 9) are consistent to within 20 m horizontally and 10 m vertically with the latter data in the vicinity of the site. The data in Figure 10 were obtained using a deep-towed 120-kHz fish (Sys120) that was poorly navigated; the latter data were subjectively shifted so as to line up with the 9-kHz data as best as possible. There may be offsets of 100 m horizontally between the 9- and 120-kHz data in the area of the source site. Furthermore, even the 120-kHz data do not have enough resolution to see ledges and other features with several meter relief.

To address the concerns about detailed bathymetry, the U.S. Navy Deep Submergence Vehicle *Sea Cliff* (DSV 4) was used to survey the proposed source site on Pioneer Seamount. Visual survey data were necessary to determine the precise location for the source and the character and roughness of the bottom, and to install acoustic transponders (expendable Benthos XT6000 10-in. glass-ball transponders) so that the source could be accurately guided to that location during deployment.

During the first cruise of M/V *Laney Chouest* on 27 September to 1 October, bad weather prevented launching an underwater vehicle; however, good bathymetry data were collected with the SeaBeam system. On the second cruise, *Laney Chouest* departed from Alameda, California, at 1600 on 13 October (all times are local unless otherwise noted). The scientific party consisted of Bruce Howe (APL-UW) and Andrew Forbes (SIO). After the survey was complete, the ship returned to Alameda at 2000 on 14 October.

On arrival at the site, it was decided to use the *Sea Cliff*, rather than the autonomous tethered vehicle (ATV) as originally planned, because a manipulator arm on the ATV had failed during pre-dive checkouts. The *Sea Cliff* was put over the side at 0137 on 14 October. The complement consisted of Pilot Frantz, Co-pilot Griffen, and observer Howe.

Transponder 1 (T1, RX 9.0 kHz, TX 13.0 kHz, 5-m tether) was deployed at 0334 on the main pinnacle at the highest point as determined from the scanning sonar and by visual observation through the portholes and using the video camera. The *Sea Cliff's* depth sensor (1.2 m above the bottom of the vehicle) indicated the bottom was at 933.3 m. Several radial lines were run to the west in an attempt to quantify the slope. This in the end was not possible because the range to T1 could not be accurately determined; the transponder did not show up in the sonar display as had been expected, and the acoustic ranging did not produce reliable results. After running the radial lines, it became clear that the pinnacle had a small plateau on its top and then steep sides with slopes greater than 15°. The relief was relatively small, with bumps/rocks about 50 cm high, not a problem for the source frame. Later, it was determined that T1 was about 5 m east of the lip of the plateau. There did seem to be a shelf of sorts to the west of the main pinnacle, at 955.6 m depth. The range of this shelf from T1 was estimated to be between 100 and 200 m, giving an effective slope to the west between 12 and 6°, respectively. Sponges and sea fans were visible on the top of the seamount, becoming sparse on the slopes. Only a few fish, crabs, and shrimp were seen.

Transponder 2 (T2, RX 9.0 kHz, TX 15.0 kHz, 10-m tether) was deployed at approximately 0600 about 20 m to the northwest; this location was determined from the transponder survey. The intention at the time was to place it to the northeast, but apparently the local current pushed *Sea Cliff* west. Current speed varied between 5 and 20 cm/s, but the current meter did not provide direction. The depth at T2 was 937.3 m. Because T2 has a 10-m tether, a location with a depth approximately 5 m deeper than T1 was chosen. Transponder 3 (T3, RX 9.0 kHz, TX 16.0 kHz, 5 m tether) was deployed at 0634 about 10 m to the southeast of transponder 1; again, its location was determined from the transponder survey after the fact. The intention had been to place it more to the south and east. The depth at T3 was 935.1 m. All transponders have lithium battery packs. Transponders T1 and T3 have enable options and should last 10 years; T2 does not and should last 5 years.

During the dive, some video footage was taken (unfortunately, the deployments of Transponders 2 and 3 were missed) as well as 44 still photographs, one of which is shown in Figure 11. The only physical sample recovered is the rock shown in Figure 12, which was collected next to T3.

After the transponder deployments were complete, *Sea Cliff* continued along the proposed cable route for a distance of about 500 m to the northeast in order to determine the character of the bottom. The bottom appeared reasonably smooth, with 30-cm-high bumps/rocks and a thin layer of sediment.

After *Sea Cliff* was recovered, transponder survey data were collected. P-code GPS, gyrocompass, and acoustic travel time data were logged as the ship moved slowly around a 1-km-radius circle centered on the site. The ship's Sonotech NS-11 acoustic ranging system was used to measure the acoustic travel times. These data were used with three independent software packages to produce relative and absolute transponder positions.

When the source was deployed, it became clear that the transponder and bottom depths determined during this survey were too shallow by about 5 m. (Furthermore, the depths from all the echosounder/sidescan/multibeam bathymetry measurements are consistently too deep, probably reflecting a bias resulting from a finite footprint sampling a steep slope.) The acoustic data collected during the *Laney Chouest* transponder survey and the depth data collected during the source deployment have been combined to produce the "best" set of coordinates. The transponder coordinates obtained using the survey program written by Howe are given in the Table 1 and are shown superimposed on the Sys120 contours in Figure 13. (The contours have been shifted by $(x,y,z) = (4,-46,-10\text{ m})$ to approximately match the transponder geometry.) The three programs gave positions for T2 and T3 relative to T1 that differed by 5 m. Two independent programs gave absolute positions for T1 that differed by 5 m. Note that tether lengths need to be added to transponder depths in Table 1 to obtain bottom depth.

Table 1. Transponder positions on Pioneer Seamount.

Absolute Positions						
Transponder	Longitude	Error (m)	Latitude	Error (m)	Depth (m)	Error (m)
1	123°26.7117´W	1.9	37°20.5550´N	1.8	934.5	0.7
2	123°26.7207´W	1.9	37°20.5632´N	1.8	933.3	0.7
3	123°26.7089´W	1.9	37°20.5483´N	1.8	938.9	0.8
Positions Relative to T1						
Transponder	x (m)	Error (m)	y (m)	Error (m)	z (m)	Error (m)
1	0.00	0.00	0.00	0.00	0.00	0.00
2	−13.26	0.24	15.15	0.23	1.18	0.83
3	4.21	0.24	−12.55	0.23	−4.45	0.84

As a result of the *Sea Cliff* survey, it was decided that the main pinnacle was the safest, least risky, choice for a site. The pinnacle is thought to be about 20 m in diameter and rises to 940.7 m at 37°20.5550´N, 123°26.7117´W. This is the location of transponder T1 as well as the best estimate of the source position after deployment.

4. PILLAR POINT SHORE CABLE AND EQUIPMENT INSTALLATION

4.1 Preparations on Shore

The sea cable to the Pioneer Seamount source is terminated at the Pillar Point Air Force Station. A plan view showing the terminal building, the cable route to the waterline, roads, etc., is shown in Figure 14. The terminal building sits on a 35-m-high bluff that overlooks the ocean; the cable route follows a path parallel to a drainage channel that carries rain runoff from all the roads down to the beach. This channel was installed in June 1995 as part of a project to fill in a ravine formed by runoff erosion. As part of this project, a conduit was installed parallel to the drainage channel to simplify bringing the cable up the slope. The conduit is made of black high-density polyethylene with a 3.5-in. OD, a 2.86-in. ID, and a 0.318-in.-thick wall. A deadman anchor (a 20-ft-long, 3-in. OD, Schedule 40 steel pipe) is buried 4 ft deep at the seaward end of the conduit.

4.2 Cable Installation

The installation of the 3 nmi of armored STC cable (called the shore cable) at Pillar Point, California, took place 4–6 October 1995 using R/V *McGaw*.

The shore cable is double armored, weighs 6 lb/ft in air and 4.8 lb/ft in water, and has an outside diameter of 2.6 in. Like the rest of the ATOC source cable, the inner coaxial core is SD List 1, 1.25-in. OD, standard undersea communications cable (the same type of cable has been used in the past for transocean telephone cables). The shore cable extends 2.4 nmi seaward.

On 29 September, the cable was loaded on M/V *McGaw* at the STC plant in Portland, Oregon, where it had been armored. The ship then transited to Pillar Point, and installation work began on 4 October. Divers first placed marker buoys for mooring anchors at four locations with sandy bottoms. These locations were slightly south of the desired position because waves were breaking on rocks to the north. Then *McGaw* deployed a 3500-lb Danforth anchor at each of these locations. The ship was moored to the anchors on 5 October at 0830 local time on a heading of 282° magnetic (298° True). Position was steady within 2 m as determined with a differential Global Positioning System (DGPS). The ship and anchor locations are shown in Table 2.

Table 2. Ship and anchor locations during installation of the Pillar Point shore cable.

Point	Latitude N	Longitude W	Depth (m)
ship	37°30.0728´	122°30.4301´	13
1	37°30.0769´	122°30.3770´	12
2	37°30.0024´	122°30.4033´	12
3	37°30.0431´	122°30.5619´	17
4	37°30.1598´	122°30.5387´	17

These positions are shown on the chart in Figure 15. After the mooring was complete, a line for pulling the cable was taken from the ship to shore by a small boat and swimmers. The cable was first put over the side at 1032. The cable was floated using air bags and guided using a small boat. The cable was pulled out of the hold both by the tension applied on the pulling line from equipment on shore and by a hydraulically powered bullwheel over the cable pan on the ship. The pulling line was fed over a quadrant block along the road, and water was continually fed down the conduit for lubrication. The bullwheel on the ship proved to be underpowered. The pulling equipment on shore also proved to be underpowered; the truck initially used burned out its transmission. Then a cherry picker was obtained from the Air Force Station, but it, too, was underpowered. Finally, the winch on a large tow truck was used to bring the cable ashore and haul the unarmored length up through the conduit to the top of the hill. The double-armored section finally reached the conduit on the beach at 1700 and was chained to the deadman anchor. The floats were cut off, and the cable sank to the bottom. During this process, two small boats worked to pull the cable slightly north. This effort was aided by the currents, which were such as to bow the cable north, closer to what appeared at the time to be the area with the least swell and deepest water.

The anchor lines were released, and the cable laying began at 1917. Almost immediately, it became even more obvious that the bullwheel was underpowered; it could not pull the cable out of the hold by itself, and thus the cable could only be pulled out by the tension of the cable in the water. This resulted in sections with slack and sections with little or no slack (i.e., with tension). Also, just after starting deployment, there was a DGPS dropout for 3 minutes, which did not help the situation.

The sea end of the cable was fitted with an acoustic release and ground line and deployed at 2345. The best estimate of the shore-cable route as laid is given in Table 3. The complete route is given in Appendix B.

Table 3. Positions of shore cable.

Point	Latitude N	Longitude W	Depth (m)
1	37°29.982′	122°29.967′	0
2	37°30.050′	122°30.170′	6
ship moor 3	37°30.073′	122°30.430′	13
4	37°29.930′	122°30.420′	14
5	37°29.710′	122°30.670′	24
6	37°29.710′	122°31.040′	30
7	37°29.840′	122°31.450′	34
release 8	37°29.868′	122°33.261′	46
final bight 8	37°29.856′	122°33.145′	46

The "release" point is where the acoustic release (used later to recover the cable for the final splice with the sea cable) was deployed. The "final bight" point is where the final splice bight was deployed as the last operation in the installation.

On 6 October, M/V *McGaw* returned to the mooring site and recovered the mooring anchors. Personnel on the shore worked at low tide to bury the cable deeper in the sand through the tidal zone. The cable was buried a minimum of 2 ft deep, and the beach was left in its original condition. A preliminary diver survey showed that the cable was buried in sand out to a water depth of 9 ft, at which point sand ended and the bottom became rocky. Basketball-sized rocks were found scattered on the bottom; the cable was shifted off any it was resting on where possible.

On 12 October, divers swam seaward along the cable from where *McGaw* had been moored in 43 ft of water. At the mooring location, the cable was found to be lying in rippled sand with 2–3 ft peaks. Approximately 100 yd east of the mooring location, in 40 ft of water, the cable encountered a flat-topped reef. At dips in the reef, the cable was suspended up to 2 ft for spans as long as 25 ft. South of the mooring location, the cable encountered smooth-topped reefs with 5–8-ft deep, 40-ft wide canyons between them, some with cable suspensions. The survey stopped at 57-ft depth. These suspensions are a cause for concern, and periodic inspections of the shore cable should be made.

4.3 Shore Equipment Installation

Upon completion of the shore-cable installation, a 100-m piece of cable was spliced to the end on shore to connect to the terminal building. This cable was buried, typically at a depth of 30 in., in a trench running from the top of the hill to the terminal building. A map of the shore facility showing the cable route is shown in Figure 14 and

photographs are shown in Figure 16. The coordinates for this section of cable are given in Appendix B. Results of resistance and time-delay reflectometer (TDR) tests of the cable were satisfactory (see Appendix C).

During the cable installation, a ground wire (#4 awg, 19 wires 0.037-in. to 0.050-in. each, black PVC jacket with a clear 0.005-in. outer jacket) was brought up the conduit with the main cable. It was connected to a grounding rod driven into the beach to a depth of 8 ft. This cable was also run to the terminal building.

During the cable installation, an enclosure was built to isolate the equipment from dirt and other disturbance (see the photographs in Figure 16). This structure is inside Pillar Point Air Force Station maintenance building 110. The enclosure is provided with 75-A, 208-V, three-phase power. A 60-A, 208-V, three-phase breaker is provided for the Ling power amplifier. A 15-A, 120-V four-socket outlet is provided for the computer rack and other electronics. The shelter has cooling fans (forcing filtered air in at the bottom and out at the top) and lighting. The cable junction box has three grounds available: power, building (a 10-ft rod just outside the building), and ocean/beach. Lightning arresters are also included. A smoke detector mounted on the inside roof of the shelter is connected to a siren and strobe light. A GPS antenna is mounted on the roof. Two telephone lines are installed for voice and data transfer.

The power amplifier and electronics for controlling the source are shown in Figure 16 as well. Schematics of the dryside electronics are given in Figure 4.

5. SOURCE AND SEA CABLE INSTALLATION

The time table for the *Independence* operation is given in Appendix A. The ship track for the cruise is shown in Figure 17. A list of personnel on *Independence* is given in Appendix D.

5.1 Navigation

The ship was navigated using differential GPS (DGPS). An Accupoint receiver was used to obtain the differential-beacon correction data (the data are transmitted by commercial FM radio stations). An Ashtech MDXII 12-channel GPS receiver was the primary navigation source; its antenna was directly over the overboarding sheave on the A-frame. Dockside tests showed that the Ashtech noise level was about 2 m rms, while that of the MariPro Motorola GPS-Engine was 5–7 m rms. DGPS and ship-heading data were logged by MariPro's navigation computer as well as by an APL-UW computer. The World Geodetic System 1984 (WGS84) was used throughout.

M/V *Independence* has twin, fixed-pitch propellers and 500-HP bow and stern water-jet thrusters. The ship has a proven dynamic positioning system. During the deployment, the weather was exceptionally good: the wind was less than 10 knots and the seas less than 3 ft; we were very fortunate! After the DGPS data rate was increased from one sample every 5 s to one sample every 2 s, the scatter plot of ship position showed a variation of about 2 m rms. At times, though, the ship would drift off 5–10 m and sometimes more, and the dynamic positioning system was adjusted manually to help bring the ship back on station; these times usually, but not always, coincided with times when the signal from the differential beacon dropped out. It seemed that the signal would drop out more frequently near sundown, just when the source was near the bottom and it was needed the most.

Acoustic tracking of the source package relative to the bottom transponders set by *Sea Cliff* was used to guide the package to Point Love. A Benthos interrogator transducer was mounted on a transducer boom 17.6 m forward and 6.3 m starboard of the GPS antenna on the A-frame; the transponder's depth was 5 m. Three transponders were on the source package (one was the acoustic release for the recovery line; see Figure 3.) The plan was to measure sing-around travel times (ship to source package to bottom transponder to ship) and use the known transponder positions and package depth to calculate the horizontal position of the package. Three transponders were used for redundancy, as well as to determine the package's orientation. For various reasons described below, the sing-around travel time to T1, Point Love, was used as the primary acoustic datum for guiding the package.

A 12-kHz echosounder was used to measure bottom bathymetry as well as to track the source as it approached the bottom.

During cable laying, the cable dynamics are such that the cable will not fall on the bottom directly beneath the ship; rather, the final location on the bottom depends on a

multitude of factors, including ship speed, cable payout speed, cable drag, etc. In an attempt to achieve the planned cable route, a cable-laying simulation program (W. McLennon, MariPro) was used in an iterative fashion to determine the ship track, ship speed, and cable payout that would place the cable in the desired location with the correct slack. The planned ship track is shown in Figure 18; the differences between the ship track and the cable route make intuitive sense: turns are exaggerated and overshot to take into account the finite fall rate and direction of the cable.

5.2 Mobilization

The ship was docked in Port Hueneme at the Naval Facilities Engineering Service Center (NFESC) facility. Preload staging by APL began on 13 October. The source system was tested on land, and then it was lowered by crane into the water from the pier and tested 18–19 October. Ground loops in the power-amplifier measurement circuitry plagued these and subsequent measurements until correctly diagnosed on 3 November at Pillar Point.

During this time, there was much discussion about the deck loading. There was concern because the cable pan would be sitting directly over the engine room, which has only minimal bracing. It was finally decided to recover and deploy the cable in two stages, rather than having all the cable on board at one time.

All of APL-UW's laboratory equipment (power amplifier, source-computer rack, navigation computers, etc.) was loaded the evening of 19 October. After the ship fueled on the morning of 20 October, general loading began at 1200. Figure 19 shows the deck layout with all the MariPro cable-handling equipment: cable chute, linear cable engine (LCE), cable pan, gantry, RB-90 winch for lowering the source package and for grappling, and a rigging van. Work went on around the clock, with six welders working continuously. Loading was complete by the evening of 22 October.

5.3 Dockside Test Deployment

A test deployment of the source package was made dockside before departure. The first attempt revealed immediately that the lowering cable had not been properly spooled under tension. The source was then deployed using the grapple wire on the second winch drum. Then the lowering wire was properly spooled (taking an extra day), and the deployment test repeated.

5.4 Testing the Source Package in Santa Barbara Channel

After the ship departed Port Hueneme late in the evening of 23 October, a test deployment of the source was made on the south side of Santa Barbara Channel at 33°56.646′N, 119°20.089′W in 805 m of water. The ship's semi-rigid inflatable boat, connected with a line to the source, was used to hold the source steady and to prevent twisting and fouling of the lowering cable and the SD electrical cable. The source was deployed to 5 m and then 114 m. After initial tests at 114 m, the source was pressurized

(using only one gas bottle). Source impedance data were logged while the source was powered by a 26-W 2.5-minute-long m-sequence. The VLA appeared to be working, after the ship minimized thruster activity to reduce acoustic noise. All other equipment was checked and was functioning normally.

5.5 Recovering the Point Sur Cable

Recovery of the 50-km (27-nmi) long section of cable stowed on the seabed off Point Sur started at the east end in 126 m of water (Figure 20). The recovery-line release worked without a problem. Lengths and electrical characteristics of the cables as recovered are given in Appendix C. The cable-route coordinates are given in Appendix E. The recovery did not go as smoothly as hoped.

F/V *Point Loma* had caught the cable in its trawl gear on 13–14 September 1995 at 36°17.91′N, 122°1.92′W in 108 m of water approximately 5.8 nmi from the landward end of the cable. *Point Loma* personnel reported that the outer jacket and shield were cut through but that the center strength member was intact when cable was thrown back. (By coincidence, the *Point Loma* was also in the area during the cable recovery and an interesting conversation took place.) The cable was found parted. It had failed under tension (as evidenced by wires that were necked down) prior to recovery (as evidenced by corrosion). At one place, it was obvious that wire rope had sawed into the SD cable in a spiral fashion, cutting through the conductors to the center steel strength wires. After the shoreward section was recovered, the acoustic release on the seaward end was triggered and the cable recovered. About 2 nmi of cable was damaged and was removed before splicing the two lengths together. The termination on the end of the Point Sur cable was tested and spliced onto the opposite end of the cable.

The complete cable was tested. The power amplifier was used to drive the 240-Ω dummy load through the cable with a 75-Hz signal at 2250-V amplitude (1600 Vrms, 4500 V peak to peak).

5.6 Source Deployment

Upon arriving at the source site, the ship enabled and interrogated the bottom transponders left by *Sea Cliff*. Replies from T3, the southeast one, were too infrequent to be of use.

5.6.1 First Attempt

The first deployment of the source on 27 October was not successful. Just minutes before preparing to lower it the last few meters, the receiver began to draw 0.95 A rather than the normal 0.7 A. The plots of the measured source impedance had changed, as well as the shape of the reflectometer return pulse. Modeling indicated that one possible explanation could be a 2000-Ω short either in the cable termination or in the T/R network on the package.

The recovery was not pleasant, as the SD cable was wrapped around the lowering cable (as expected). When the source package was back on deck, it was determined that water had leaked along the strands of the steel strength member in the SD cable and into the termination. The steel strands are inside a watertight copper tube that forms the inner conductor of the cable. The water had entered the cable at the point where it had been damaged by the fishing trawl and had wicked through the dry section and termination that had been spliced on. In hindsight, this was an obvious possible failure mode—but in all the earlier deliberations, it was assumed that the center of the cable would be dry. In all our discussions with AT&T, there was no mention of such a problem. The cable was reterminated by directly splicing it to the pigtail/connector that mates to the T/R case. A small brass cap was brazed over the end of the inner conductor to prevent water from wicking out of the strands again. Aquaseal was used to obtain a watertight seal. After the cable had been reterminated, it was discovered the next morning that the temperature sensor had failed. It was replaced with a spare (more will be said about this later). Also, during the first deployment, the two (recoverable) TR-6000 17-in. glass-ball acoustic transponders broke free of the source frame. They were reattached permanently for the second deployment.

As the first and second deployments were very similar, only the details of the second deployment on 28 October will be given.

5.6.2 Lowering the Source

The source package was deployed on a lowering line consisting of 46 m of nylon line which served as a shock absorber followed by a steel strength member (low-twist crane wire). The SD sea cable was married to this line with tape; in addition, Yale Kevlar grips were applied every 300 m to carry the weight of the slack SD cable. The SD cable was run through the linear cable engine and over a quadrant block while the steel wire was payed out through an overboarding sheave on the A-frame using a drum winch. The source was lowered to approximately 4 m and then to 46 m for about 10 minutes of testing at each depth. More tests were made at 114-m depth. During the entire deployment, the ship held position over Point Love as best as possible using DGPS. This typically was within 2 m rms (as measured by the spread of points on the display), but at times the spread was up to 30 m peak to peak.

The source was then lowered in a nearly continuous fashion, with stops only to put on the Yale grips, to 896 m, approximately 25 m above the Point Love transponder. This took 2.5 hours. As the source was lowered, its depth was determined both acoustically by acoustic ranging to the transponders and on an echosounder and manually by using a spectrum analyzer to monitor the pressure signal from the depth sensor on the source package. The latter was necessary because the hydrophones were saturated (either by ship noise or the ground-loop problem) and saturated the amplifier in the dryside receiver electronics. The tilt was monitored acoustically.

5.6.3 Positioning the Source

The source was lowered to 914 m and held there approximately 1.5 hours while the navigation was checked. To reduce confusion, it was decided to interrogate and track only the recovery-line release/transponder on the source package. We watched the sing-around travel time (ship to source to T1 to ship) for a minimum travel time. On the echo-sounder, it was possible to see both the source package and the bottom; the latter was at 945 m according to the echosounder. During the afternoon, the DGPS signal was dropping out, and each time the ship would drift off station about 10 m before the DGPS returned (usually in only tens of seconds). It was not possible during the operation to draw any conclusions about the time constant of the source motion, given the small movements of the source. There were no obvious correlations between the measured travel times and the distance of the ship from Point Love. Plots of DGPS ship position and acoustic travel times are shown in Figures 21 and 22, respectively. In the plot of ship position, there is a period of about 1 hour (at the beginning of the plot) when the variation in the positions was only several meters. Later, though, the peak-to-peak variation was as large as 30 m. In the time interval 1821–1832 (local time; 0121–0132 UTC), the excursions were about this much, and the sing-around travel times (in terms of range) show significant deviations of 5–10 m.

The acoustic tracking results proved to be somewhat confusing at the time. Once the source was down, it became readily apparent that biases on the order of 5 m in the various depth estimates confused the acoustic tracking effort. The horizontal-position calculation that was being used depended on knowing the accurate depths of all instruments. In hindsight, the slant range from the package transponder to T1 should have been calculated from the sing-around travel times and the direct times from the ship to the package *and* the bottom transponders, so that all measurements were made with a common deck unit in the acoustic domain.

5.6.4 Planting the Source

The ship seemed to be holding station quite well between 1832 and 1900 local time. Travel times were steady. Then there was a brief loss of the differential signal, and the ship drifted off slightly. At 1913, the captain said he felt he had the ship back on station in a stable mode, and the order was given to begin lowering the package to the bottom. The descent rate was 0.18 m/s. The descent is obvious in the plots of the acoustic travel times (Figure 22). During this time, the DGPS ship position varied by about 10 m (Figure 21). There was a brief pause of about 1 minute at 925.5 m. The acoustic tilt data and the line tension gave the first indications of touchdown at 1916. The bottom depth was 941 m, based on the pressure-sensor and travel-time data, and the tilt was 5.8°. At this time, about 20 m of cable was payed out, and the ship started to move off to the northeast. This payout was a compromise between having just enough cable to reach the bottom (3 m for stretch in the nylon and 4 m from the top of the structure to the bottom) and paying out enough cable so as to be sure the structure was not pulled horizontally. Thus

there is probably 13 m or more of cable on top of or around the source package.

The cable route was followed until the ship was about 380 m to the northeast at a saddle point in the bathymetry (point 4 in the cable route, Appendix B). The ship held station at this location until the source was pressurized and testing was complete. The tilt and depth data were monitored to be sure they were not changing. The source impedance was measured. The VLA hydrophones were no longer saturated, and the signals appeared stable; both whale and RAFOS sound sources were heard (at least that's what they appeared to be to the untrained ear). The tilt and pressure signals appeared stable and reasonable, but it was noticed (at 2010 local time) that the temperature signal had disappeared from the sea-cable signal spectrum. Because of the temperature sensor's failure during the first deployment attempt, this raised the specter of a nonrandom problem. Also, the batteries powering the acoustic transducer of the tilt system appeared to be fading, as the system would transmit only when dc power was being sent down the cable. Apparently, there was enough battery power for the acoustic transducer itself but not for the associated electronics which then drew power from the cable; this was expected.

Subsequent analysis of the travel-time data indicated that the release transponder on the source package is directly under T1. The estimated slant range between T1 and the source package is 3 m; however, we know that T1 is 5 m above the bottom. This 2-m inconsistency is a measure of the uncertainty in the position. At this time, the best estimate of the source coordinates is the position of T1, 37°20.5550′N, 123°26.7117′W ± 4 m. The estimated bottom depth is 940.7 m, and the center of the source is at 938.7 m ± 2 m. In UTM, Zone 10, horizontal coordinates, the position is 460566.6 m Easting, 4132965.8 m Northing.

5.6.5 *Pressurizing and Testing the Source*

The acoustic signal was sent to actuate the gas valve and pressurize the source at 1944. The source impedance was monitored during this time. The impedance plots were at first changing in the way predicted by Kurt Metzger's model, but then they started to change in an unexpected way. This produced some consternation, to say the least. All indications from the acoustic valve were that it was working (it was turned on several times, and it sent confirming signals). After about 45 minutes, the impedance plots (Figure 24) had stablized. Some of this apparently erratic behavior may be explained by assuming the bubble cloud from the excess gas escaping around the source affected the impedance measurement by changing the mechanical characteristics of the source near its resonance frequency.

A short test 75-Hz signal was sent, received on monitoring hydrophones suspended from the ship (one at 61 m and one at 500 m), and processed. The absolute signal level approximately matched that expected, given the nominal drive voltage and distance (measured by the travel time).

5.6.6. *Further Testing of the Source*

A short test m-sequence signal was sent, received on the monitoring hydrophones, and processed. The correlation peaks looked reasonable (see Figure 24a), with the absolute signal level (26 W) matching that expected given the nominal drive voltage (263 Vrms, 400 V peak for 27 nmi of cable) and distance. Further analysis revealed that the correlation peak was quite "clean," with a 3-dB width of 30.8 ms and low shoulders (a 20-dB width of 58.3 ms). This width is smaller than that predicted for a free field standard m-sequence signal (a 3-dB width of 37.5 ms and a 20-dB width of 85.8 ms). The measured spectrum is indeed broader, with two peaks and a very shallow valley between them (Figure 25); the energy in the "new" peak on the high-frequency side of the main peak helps sharpen the time-domain pulse. This peak width of 30.8 ms can be compared with the peak width of 28.3 ms obtained in the free field using signal shaping during the ATOC Acoustic Engineering Test (Howe, 1994). After much discussion, one possible explanation for these effects—the unexpected shape of the impedance plot, the spectral plot, and corresponding time-domain pulse—may be the presence of the bottom, which is not included in the source model. More will be said about this later.

Several other brief, low-power, test signals were sent to characterize the source further. Signal shaping was performed, but the results were inconclusive, most likely because of hydrophone and/or ship motion. Given the excellent pulse shape obtained without signal shaping, it was decided to transmit only the standard (unshaped) m-sequence described in Appendix G.

During this time when the ship was holding station, two transmissions were made to test the source under operational conditions. Each lasted 20 minutes; the first was at 26 W and the second at 260 W. Twelve test transmissions were made over the next 4 days to verify the source's performance as splices were made, etc. (see Section 6 and Appendix H).

Before the ship moved off to start the cable laying, the acoustic valve was closed (re-armed) and the closure verified. After 3 days, one set of corrosion links parted, releasing weights and enabling the main valve/plug at the bottom of the source cavity to close; after 5 days, another set parted, disconnecting the high-pressure gas lines from the regulator. Also after 3 days, yet another set of corrosion links parted, letting a 50-lb weight (two lead balls) secured to the frame fall to the bottom; this weight is secured to the small pressure-relief pin/plug at the base of the source cavity. When the source is recovered, this pin will be pulled out, permitting the gas to escape as the source is raised.

5.7 Cable Laying Toward Pillar Point

The cable route given in Appendix B was followed in laying the cable to Pillar Point (with the ship track modified per Figure 18). The MariPro navigation computer provided the necessary display for navigating the ship. The computer controlling the cable determined the amount and rate of cable payout, given the ship's position, velocity, the desired slack, etc. The lay was uneventful, except for one unplanned stop for 30 minutes

about 1 hour into the lay. The stop was necessary to repair a gouge in the cable jacket that had not been detected on recovery. This stop undoubtedly produced an anomaly in the cable route on the bottom, but without additional calculations with the cable-laying program, it is not possible to say what this anomaly would be. Along the seamount, the ship speed was 0.5 knot; it then increased to 1 knot over the flank and to 2 knots up the continental slope. According to the linear cable engine (LCE) counter, 44,812 m (24.19 nmi) of cable was laid to this point. The TDR length estimate is 47,509 m (29.65 nmi). (Estimated cable-length errors are about 5%; inconsistencies between LCE and TDR reflectometer measurements abound, as shown in Appendix C.) The end of the cable, equipped with a ground line and an acoustic release, was deployed in 500 m of water.

Five test transmissions were made during this time to verify source operation, since if problems were found, it would still be relatively easy to recover the cable and source.

During this time, the receiver was also checked. The pressure and tilt signals were stable, but the hydrophones were partially saturated. It is felt that the reason for this, determined later at Pillar Point, was a ground loop in the power-amplifier monitoring circuit (more will be said about this later).

5.8 Recovering the San Simeon Cable

Grappling was necessary to recover the cable stowed off San Simeon, since there was no recovery release. The cable route is shown in Figure 25, and the cable information is given in Appendix C; the cable-route coordinates are given in Appendix F. Recovery began at the shallow (550-m), southern end. Grappling of the nylon recovery line was successful on the first try. Cable recovery was done at 2 knots. After the correct length was recovered, the cable was cut and the wet end sealed before being lowered back down with the nylon recovery line. This cable was in excellent condition; mud was found on the grappling chain.

The portion of the San Simeon cable recovered was 47,500 m (25.64 nmi) long according to the LCE and 48,183 m (26.01 nmi) long according to the TDR. Using the TDR measurements, this leaves 20,960 m (11.32 nmi) (see Appendix C).

5.9 Laying the Second Cable Section

After the ship returned to the end of the sea cable, the recovery line was released, and the cable end was brought aboard. Source impedance and receiver tests were made, and the results were found to be the same as the last time. The sea cable and the San Simeon cable were spliced together, and the source package was tested again at low level.

Two additional test transmissions were made later in the day, in coordination with marine mammal observations.

The cable lay to Pillar Point was relatively simple, being straight and in shallow water. The LCE counter showed 42,875 m (23.15 nmi) of cable deployed. It took 7.5 hours to lay this cable, at a rate of 3 knots.

On completion of this cable lay, before the recovery of the sea end of the shore cable, a test of the receiver showed that the hydrophones were saturated to the extent that they affected the stability of the pressure and tilt channels. Source impedance measurements showed no change relative to prior measurements.

Splicing of the sea cable to the end of the shore cable took place in approximately 46 m of water over a sandy bottom. The recovery line with the acoustic release on the seaward end of the shore cable was activated with a command from the ship, and the ship's boat retrieved the float and brought the line aboard. Once the end of the shore cable was aboard, it was tested in coordination with the shore party in the terminal building. The sea cable was cut and spliced to the shore cable while the ship held station. Upon completion of the splice, the shore party tested the source impedance and checked the receiver. The latter was still saturated. This final bight of cable was then deployed.

There are two estimates of the total cable length (see Appendix C). Using the measurements by the counter on the linear cable engine as the cable was being deployed, the estimated length is 93,189 m. Using the time-delay-reflectometer data showing a measured round-trip travel time of 968 μs, the estimated length is 95,890 m, based on a propagation speed of 99.06 meters per microsecond of round-trip travel time. This is 657 m (0.7%) longer than the planned length based on geographical distance, bathymetry, and cable slack.

5.10 Return Transit and Deep Stowing of Extra Cable

Most of the scientific personnel disembarked at Pillar Point before the ship left the operations area the morning of 1 November for Port Hueneme. During the transit, the excess cable was laid in deep storage off San Simeon with a 3000-ft ground line attached at one end (see Figure 25 and Appendix F).

5.11 Demobilization

The ship docked at Port Hueneme at 1230 on 3 November. Unloading was complete by 1700 on 4 November, and the decks were clean and painted by 7 November.

6. SOURCE AND RECEIVER PERFORMANCE

After the scientific personnel arrived at the Pillar Point facility, three test transmissions were made to verify source operation while M/V *Independence* was still in the operational area (see Appendix H for a summary of the test transmissions). During this time, work continued on localizing the grounding problem. On 4 November, it was determined that a ground loop existed in the power-amplifier monitoring circuit. Isolating the circuit with isolation amplifiers eliminated the symptoms, but probably not the cause. (There is also still some high-frequency noise on the monitor signals caused by the rms voltmeters on the power amplifier's front panel; filters should be installed.) After the ground loop was fixed, Kurt Metzger's impedance measurements (Figure 26) agreed with independent ones made by Gary McGlasson (APL-UW) to within about 1%. For the nominal 260-W signal, the power-amplifier rms voltage and current are 1173 V and 4.5 A, and the electrical power is 3735 W.

After the installation of the isolation amplifiers, the receiver was no longer saturated: the pressure, tilt, and pilot signals were stable and clean, and the hydrophones signals sounded like ocean ambient noise. Soon thereafter, however, Kurt Fristrup (Cornell University), while installing a data-acquisition system to monitor marine mammals with the VLA, noticed popping and crackling sounds on the hydrophones. As there were no longer any APL-UW personnel on site, this was investigated from APL-UW remotely. It was determined that there was indeed noise on some of the hydrophones. It was highly correlated between hydrophones, with a decorrelation time of 2 ms, indicating that it was electrical in nature and not an acoustic signal (since the hydrophones were separated by 33 m). By removing the component common to all signals, what appeared to be useful ocean noise data was obtained (as evidenced by the spectra and by listening). Also, the noise was intermittent; there were gaps of several seconds when noise was absent and reasonable ocean noise spectra could be measured. With time, though, all the hydrophones became noisy and the "good" gaps disappeared.

To complicate the situation, on 20 November the impedance function of the source began changing. The frequency of the source-impedance measurement was increased to once every half hour. The receiver was left operating for the 20 minutes between measurements. In an effort to localize the cause of the change, the receiver was turned off (no dc power was sent down the cable); after a few hours, the source impedance seemed to stabilize back closer to its original shape. Also, on 21 November, the receiver started to draw a variable amount of current, peaking at 0.95 A rather than the normal 0.70 A, and the sensor frequencies became erratic. Primarily because of the latter, but also because of all the problems described above, the receiver was turned off permanently the afternoon of 21 November. No really satisfactory explanation of why the receiver should affect the source-impedance measurements has been found (if, indeed, there was a real correlation). Kurt Metzger has suggested that the dc power affected, via electrolysis, the condition of the return shield on the cable, thereby affecting the ground for the source as well.

While the receiver was working, pressure and tilt were monitored on an hourly basis for 4 days. The pressure signal had a mean of 941.7 m (implying a bottom depth of 942.6 m) and a semi-diurnal amplitude of approximately 0.7 m. This tidal elevation signal could explain some of the inconsistencies in estimates of various vertical positions. The tilt signal was constant at $5.88 \pm 0.02°$.

During December and January, the source impedance function changed slightly; then on 31 January, just at the end of a sequence of transmissions, there was a step change (Figure 26). The measured impedance is now closer to predictions (for no bottom), and it would appear that the resonance peak is broader, as more frequencies are now contained in the resonance loop. The implication is that, somehow, the mechanical characteristics of the source have changed. As the receiver has been off the entire time, there must be some other reason for this. As of this writing (April 1996), there is still no satisfactory explanation.

The signal delay through the source was measured during the Acoustic Engineering Test as 20.4 ms. The delay through the Pillar Point–Pioneer Seamount cable is 0.484 ms, giving a total source delay of 20.9 ms. Signals are transmitted exactly on the hour (typically). Total travel time is then (receive time – receiver delay) – (transmit time + source delay), where the receiver delay depends on the receiving electronics, cable, and signal processing.

Figure 27 shows the ETOP05 bathymetry of the Pacific plotted using a Lambert azimuthal map projection with the origin of the projection at the source location. Using this projection, geodesics originating at the source are straight lines. Figure 28 shows the lower-turning-point depth of the steepest nonbottom-interacting ray possible, as a function of radial distance and azimuth from the source. As the radial distance increases and, say, a seamount is encountered, the depth of the lower turning point of this limiting ray at the point just beyond the seamount is equal to the depth of the seamount. We call this a shadow plot. If a receiver is placed where there is color, it should hear a signal; the deeper the lower-turning-point depth at the receiver, the more rays/modes and vertical ocean structure can be sampled and resolved. The total area ensonified is 1200 Mm^2.

Three circles are drawn, at radii of 355 km, 1086 km, and 3127 km, where the expected signal-to-noise ratio for a single hydrophone (receiving the standard 260-W, 20-minute, m-sequence signal with 46-dB processing gain) is 40, 30, and 20 dB, respectively. The signal falls below the assumed 75 dB re 1 $\mu Pa/\sqrt{Hz}$ noise level at a 170-km radius.

7. DISCUSSION

After such a major operation, it is worthwhile to reflect on what still needs to be done, what was done well, and what was done poorly and could have been done better.

As of this writing, the source is still working, transmitting at 260 W for 20-minute periods every 4 hours on a transmission day. The transmission schedule is being coordinated by the Marine Mammal Research Project (MMRP) so as to coincide with aerial surveys. Initial results from the aerial observations indicate no discernible effect of the transmissions on the behavior of marine mammals. This statement is, of course, subject to the caveat of waiting for a longer time series as well as more detailed analysis. The signals are being heard on a VLA off Hawaii 3 Mm away and on Navy receivers around the Pacific, some as far away as 5 Mm. A VLA near Christmas Island at a range of 5 Mm is also receiving the source signals. The preliminary data indicate that only upward-going energy is propagating away from the source. It appears the that topography in the vicinity of the source is stripping out the downward-going energy.

The biggest risk to the system now is possible fishing-related damage to the cable. To minimize this possibility, the ATOC Project Office at SIO has contacted ten fishermen's associations (see Appendix I) and has sent out 250 nautical charts with the cable route drawn on them and a writeup describing the route and giving the coordinates. The latter were also published in three area newspapers. There will be a continuing effort to keep in contact with these organizations periodically. Furthermore, there was enough media coverage of this event that most fishermen along the coast should have read about it and, if concerned, contacted either their association or the ATOC office directly.

The experience with *Sea Cliff* revealed the difficulty in navigating a manned submersible without a well-defined transponder net. With this experience, we could go back and do a better job. The acoustic navigation could have been improved by understanding the on-board system better and by better predive planning. The dead reckoning could have been improved by attempting to measure the current vector using the submersible itself and then taking the current into account. More bottom photographs and video footage should have been taken, with better annotation. For a job like this, an unmanned submersible would have been better for two reasons: more time could be spent on the bottom, and one would actually have better visual displays. The tiny portholes on *Sea Cliff* and the reduced visibility are a real limitation; an unmanned vehicle (such as the ATV) has multiple cameras and more lighting. With more time on the bottom, more accurate navigation would have been possible, if only by visually identifying features.

The survey of the transponders could have been improved by obtaining a direct measure of the time delays of the instruments.

We still have only a rough idea of the bathymetry around the source, at least on horizontal scales less than 100 m and vertical scales less than 30 m. The relative features in Figure 10 (the high-resolution 120-kHz bathymetry) are roughly consistent with the *Sea*

Cliff observations. Figure 13 shows a guesstimate of the position of the source relative to the high-resolution bathymetry, based on the *Sea Cliff* observations that T1 was about 5 m east of the west edge, that T2 was on the northwest slope 5 m deeper than T1, and that T3 was about 4 m deeper than T1 and to the southeast.

During the time at Pillar Point immediately following the installation, we observed higher swell and breakers along the cable route than ever before. In hindsight, more research should have been done on the wave climate and the sand conditions near shore, although politics as much as anything drove the selection of Pillar Point. The high swell and breakers affected the placement of the anchors and M/V *McGaw*, but, fortuitously, the current seemed to push the first section of cable north as it was being sunk. The pulling power required was grossly underestimated, although, again fortuitously, the resulting delay in getting an appropriate winch gave time for the abovementioned current to develop. The underpowered bullwheel on M/V *McGaw* was more serious because it meant that the entire cable length seaward of the mooring was laid with little or no slack and probably under tension. This does not bode well for the sections of cable that are suspended. Annual inspections are recommended to see if the cable is being damaged at these suspensions near shore and in shallow water. There was one note of optimism in the diver's report—that the cable was already cutting into the rock (one-half diameter in a week) with no visible damage to the cable. This would indicate the rock is very soft, and maybe the cable will continue cutting until it stablizes itself. To aid diver inspection of future cables, it would help to place tell-tale streamers at frequent intervals (20 ft) with marks on them to indicate the depth of the buried the cable.

Based on the experience of this cruise, and cable deployments from USNS *Albert J. Meyer*, it is obvious that the very beginning of a cable-laying operation needs to be well coordinated. Both the ship velocity and the cable payout speed need to be carefully planned, and the plan followed. Having the excellent dynamic positioning system on M/V *Independence* helped this situation. The dynamic positioning was a real boon in placing the source in the right spot. Our success in getting the source to the correct location was probably due as much to this as to the acoustic tracking. Possible ways to improve the latter have been mentioned above. The dropout of the differential beacon signal was a problem; we should have used a dedicated system guaranteed for the distance offshore. The echosounder worked remarkably well in tracking both the package and the bottom.

The discrepancies between the cable lengths measured by cable engines (LCEs) and by time-delay reflectometers (TDRs) are disturbingly large. It is not clear what to do about this, other than to try and calibrate one against another, and ideally both against a better standard. Putting marks at equal intervals on the cable would at least indicate whether the payout count was the same as the payin count.

It was evident that more planning should have gone into the mobilization. The question of deck loading was not addressed soon enough. Also, a day was lost because the wire-rope lowering line had not been spooled on the winch under tension.

The cable should have been inspected better when it was being recovered so that the deployment did not have to stop for repair (as was the case on Pioneer Seamount). Some sort of cable cleaning and drying ought to be done before recovered cable goes into the LCE, something more sophisticated than a rope looped around the cable (which can and did jam on one occasion, pulling the jacket back many feet).

The failure of the receiver was disappointing. The fact that the first temperature sensor flooded, and the second sensor failed just after deployment, is a strong indication that a problem existed with the temperature sensor. The first sensor housing was tested at 1000-m pressure at APL. After 10 days the pressure started dropping; on inspection, tissue paper at the probe end was found to be wet. This is consistent with what appeared to be galvanic corrosion products found on the probe. The hydrophone failure symptoms are indicative of a leak in the main VLA connector or in all the individual hydrophone connectors. It is possible that the temperature sensor and VLA failures are related.

It is clear that we need to learn more about the impedance/admittance measurements and what they can and can't tell us. How should the effect of the bottom be modeled? What is the effect of only partially filling the cavity with gas? How should bubbles around the source affect the impedance? How does one infer acoustic bandwidth from the impedance measurements? The change in impedance on 31 January brought the source characteristics closer in line with those predicted assuming no bottom. It is as if the source cavity had (finally) filled with gas. This, too, remains a mystery.

Lastly, it would be useful to quantify the effect on the bathymetry signal as a function of azimuth. This could be done either acoustically ("calibration") or by measuring the bathymetry accurately enough that predictions made with acoustic models using the bathymetry are believable.

In summary, the installation was successful. The source is transmitting and being "heard" across the Pacific. Well done to all!

8. REFERENCES

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Figures

Figure 1. Photograph of the Alliant Techsystems HX-554 acoustic source. The outer protective boots are absent, showing the ceramic and spacer bars.

Figure 2. Photograph of the source package on the fantail of M/V *Independence*.

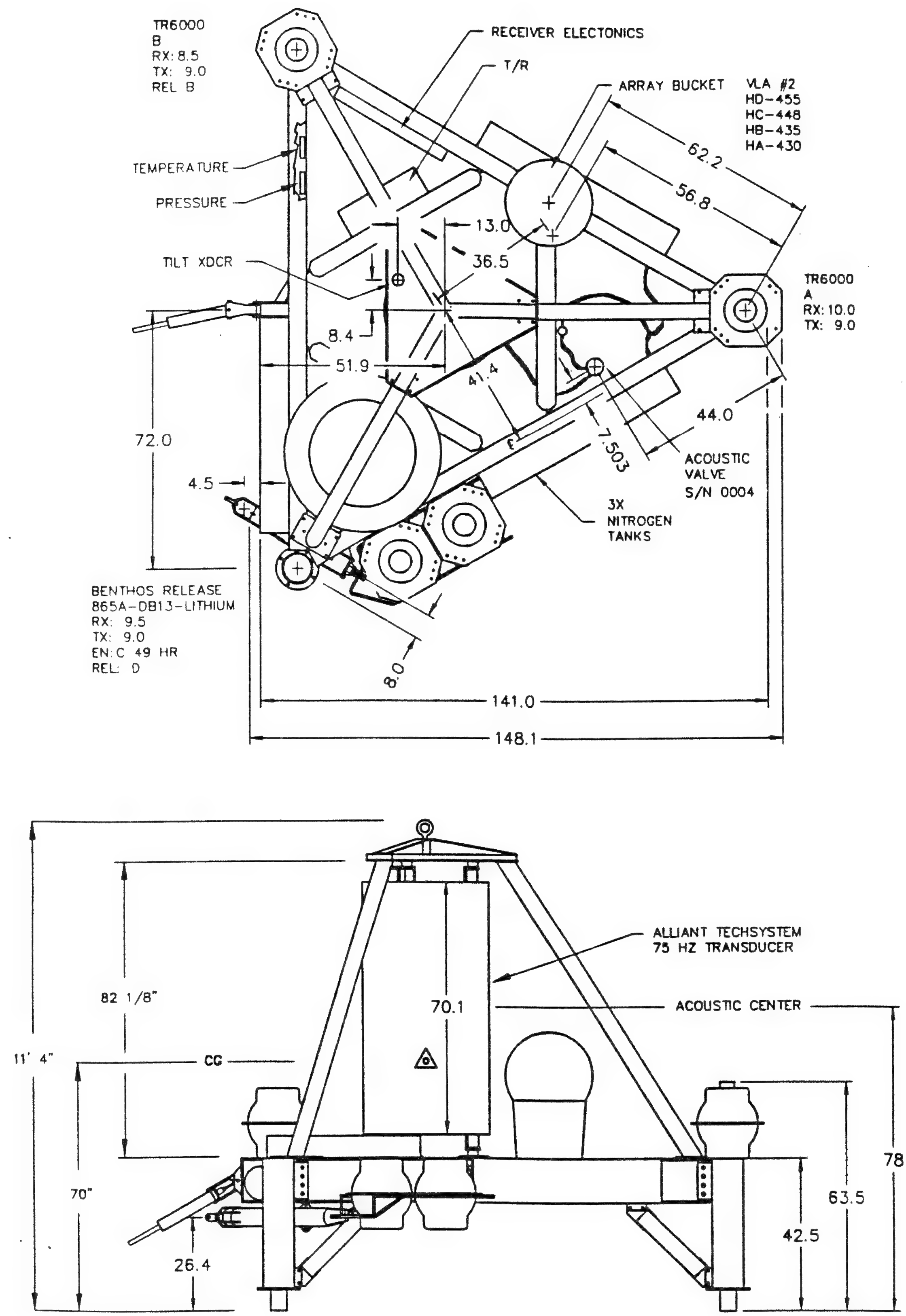
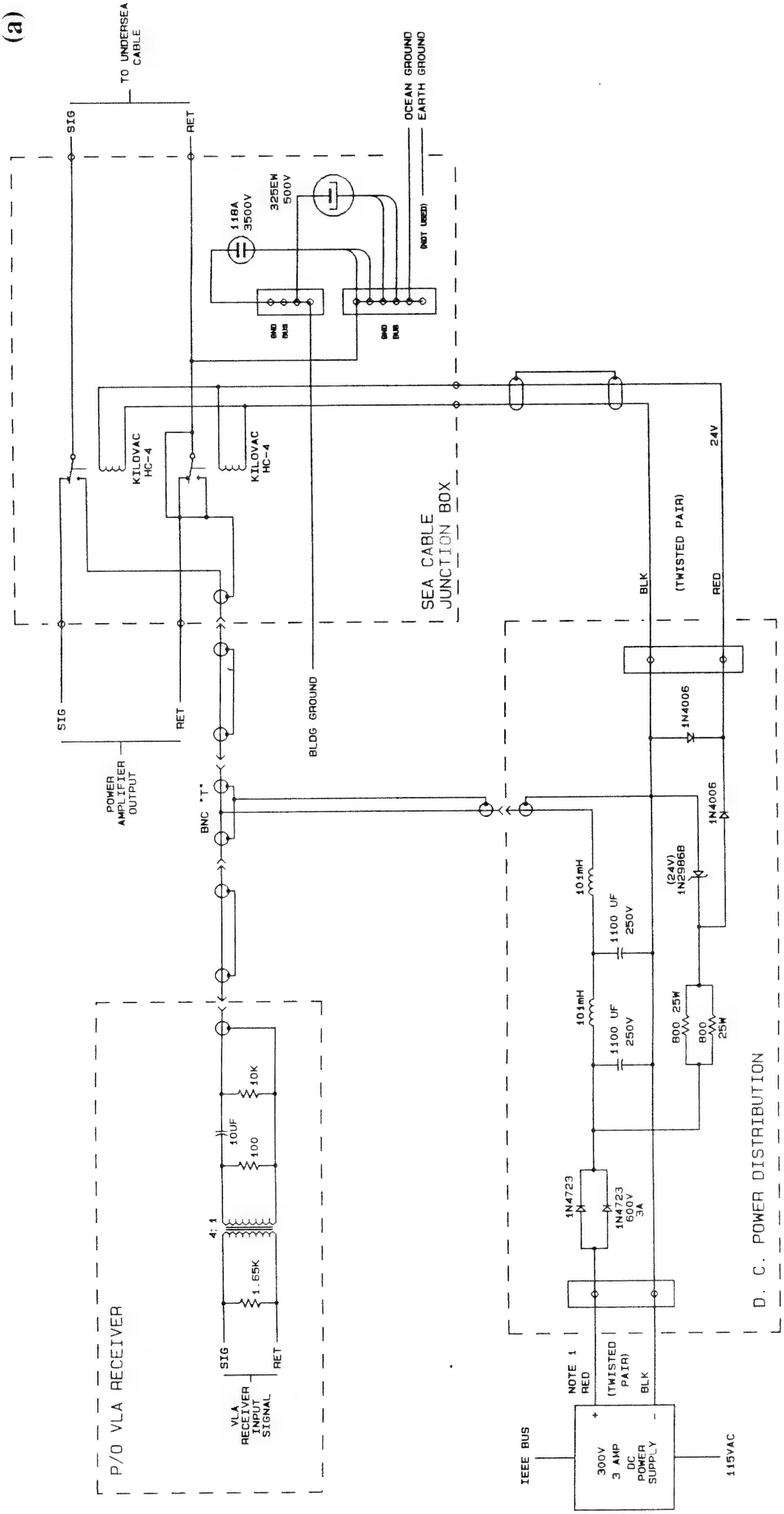


Figure 3. Line drawing of the source package. Dimensions in inches.

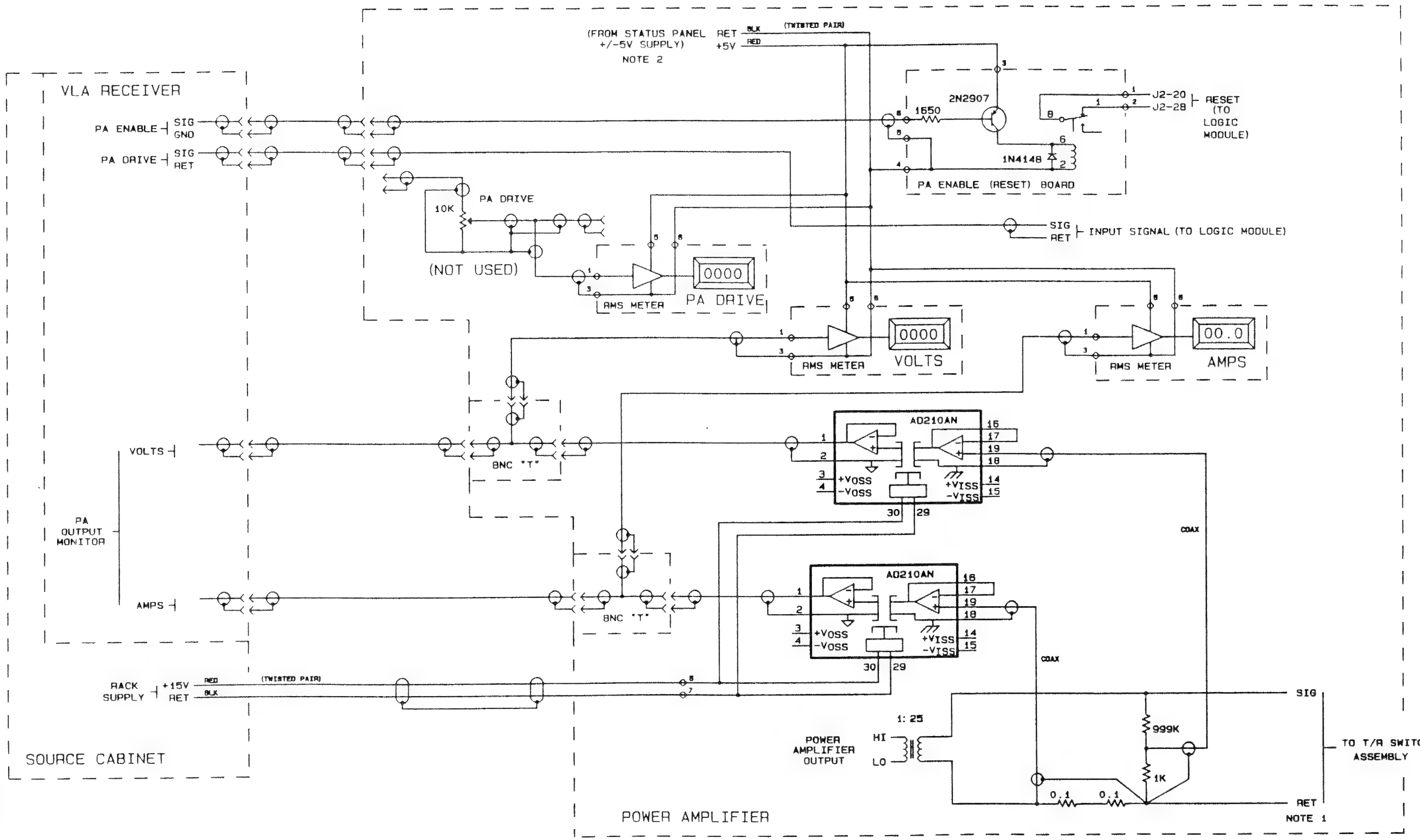
(a)



NOTE 1: POWER SUPPLY OUTPUT IS 132 VOLTS FOR CALIFORNIA INSTALLATION (50 MILE SEA CABLE).

Figure 4a. Electrical schematic of the shore cable transmit/receive interconnections.

(b)



NOTE: 1. POWER AMPLIFIER RETURN GROUNDED TO CHASSIS VIA T/R SWITCH ASSEMBLY.

2. +5V SUPPLY RETURN IS GROUNDED TO CHASSIS AT STATUS PANEL LOGIC BOARD.

Figure 4b. Electrical schematic of the shore facility power amplifier/VLA receiver interconnections.

(c)

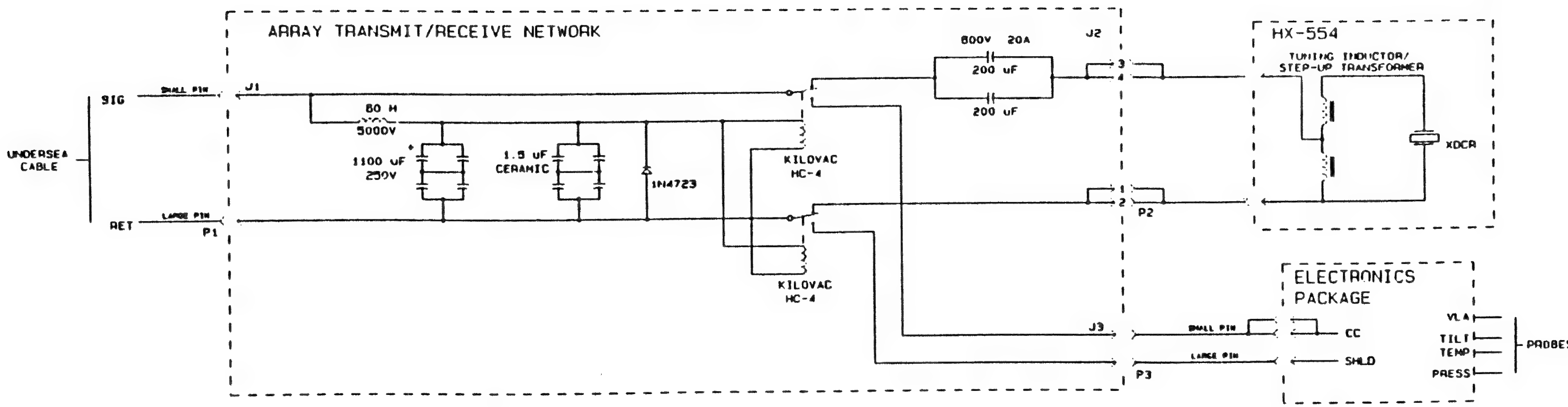


Figure 4c. Electrical schematic of the wet end transmit/receive network, the source, and the receiver electronics.

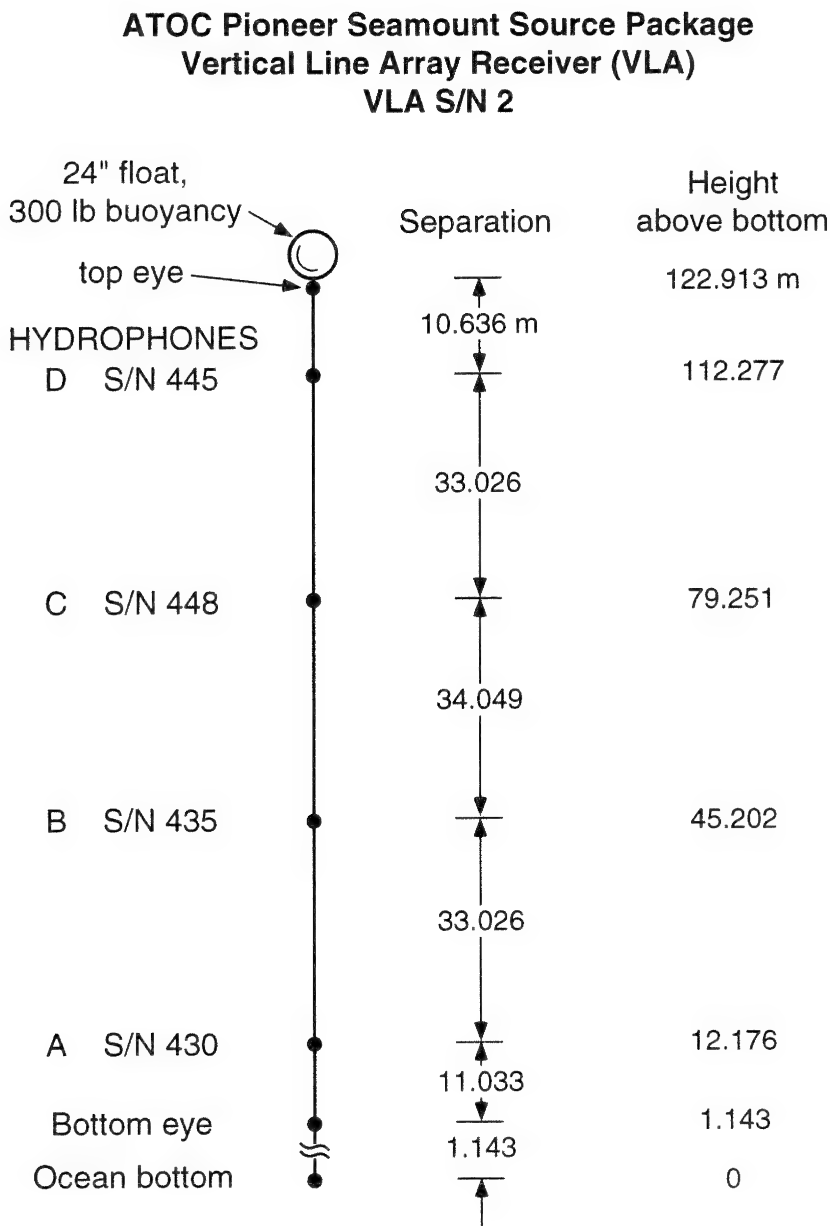


Figure 5. The Vertical Line Array (VLA).

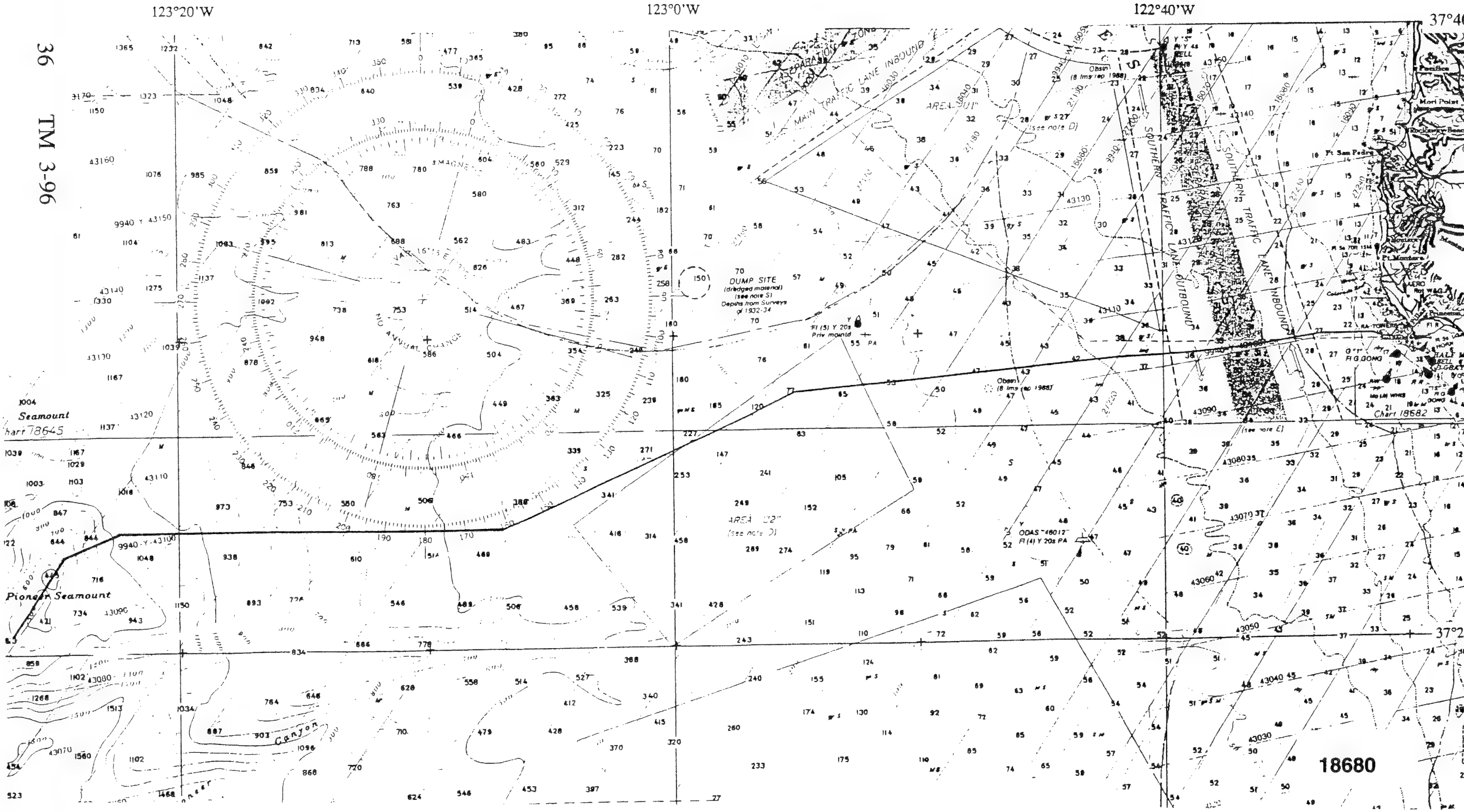


Figure 6. Cable route from Pioneer Seamount to shore.

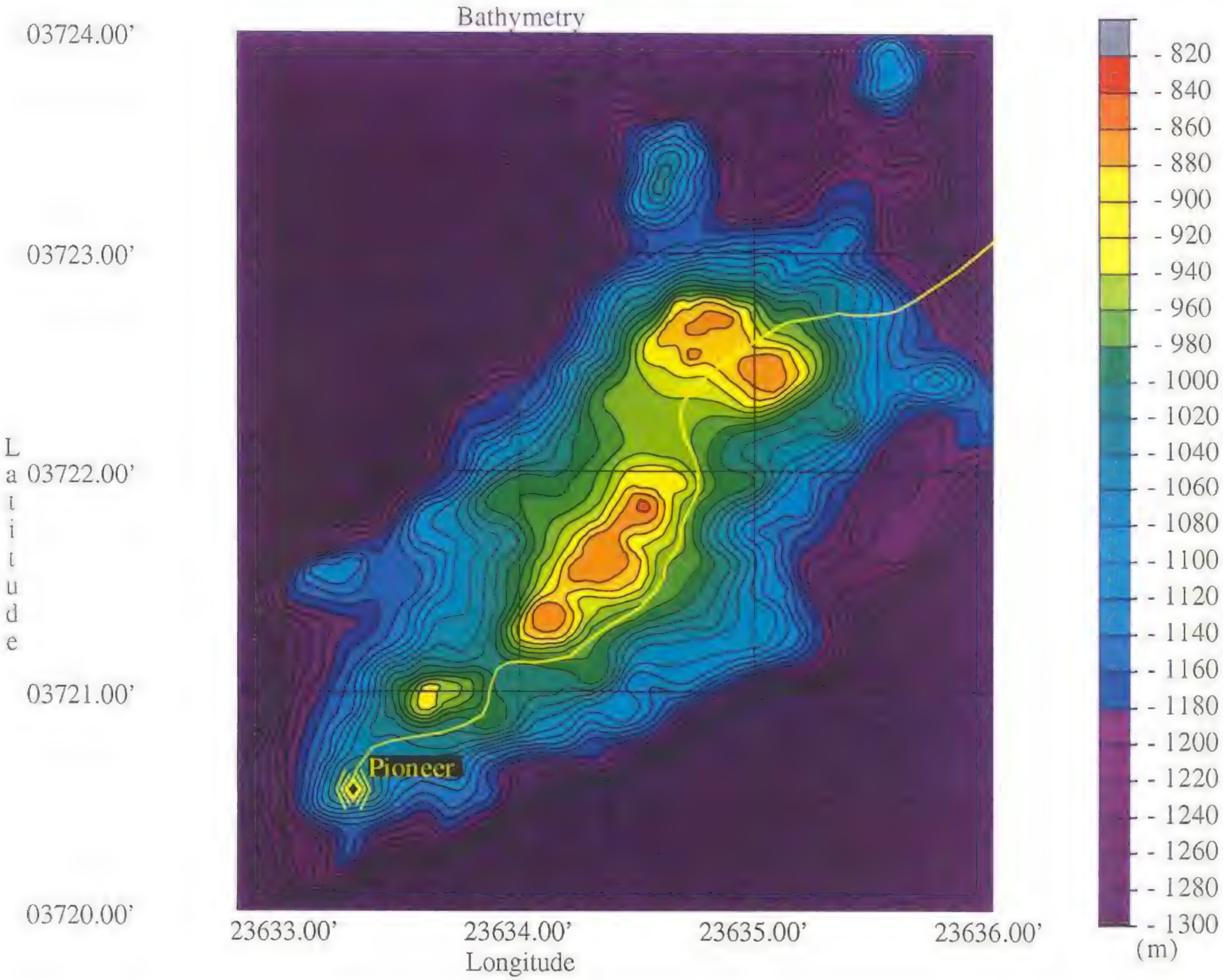


Figure 7. ATOC source site on Pioneer Seamount and cable route over the seamount.

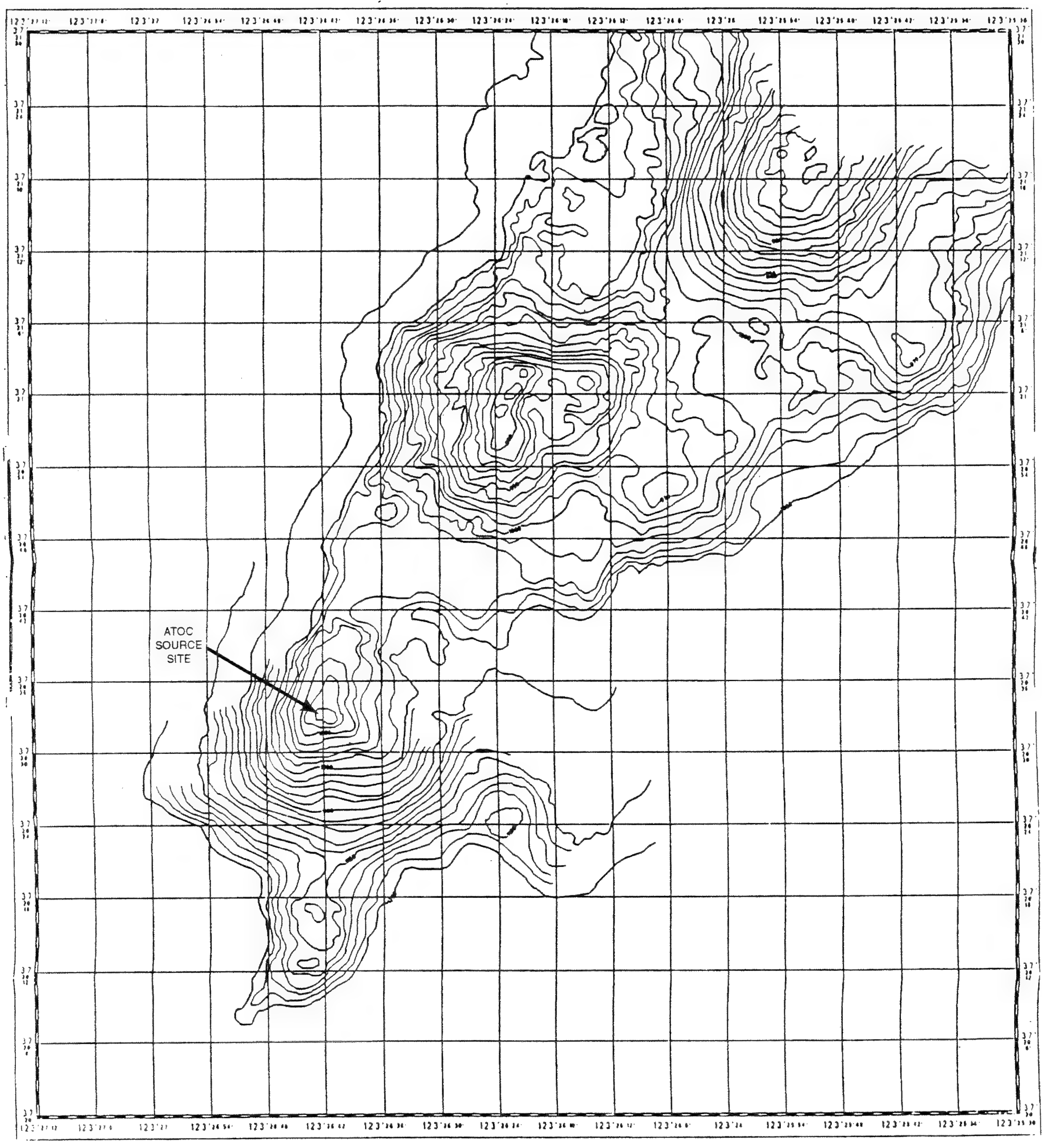


Figure 8. Bathymetry in vicinity of ATOC source site on Pioneer Seamount. The bathymetry was obtained by Seafloor Surveys International, Inc., using a 9-kHz sidescan sonar towed 100 m behind and below the survey vessel. The position of the latter was determined with Starfix (± several meters). The lower left and upper right corners of the chart correspond to 37°20′00′′N, 123°27′12′′W and 37°21′30′′N, 123°25′30′′W, respectively. Grid lines are 6 seconds apart (600 ft, or 182 m, in latitude) and the contour interval is 10 m. The depths are uncorrected; subtract approximately 12 m to obtain the corrected depth.

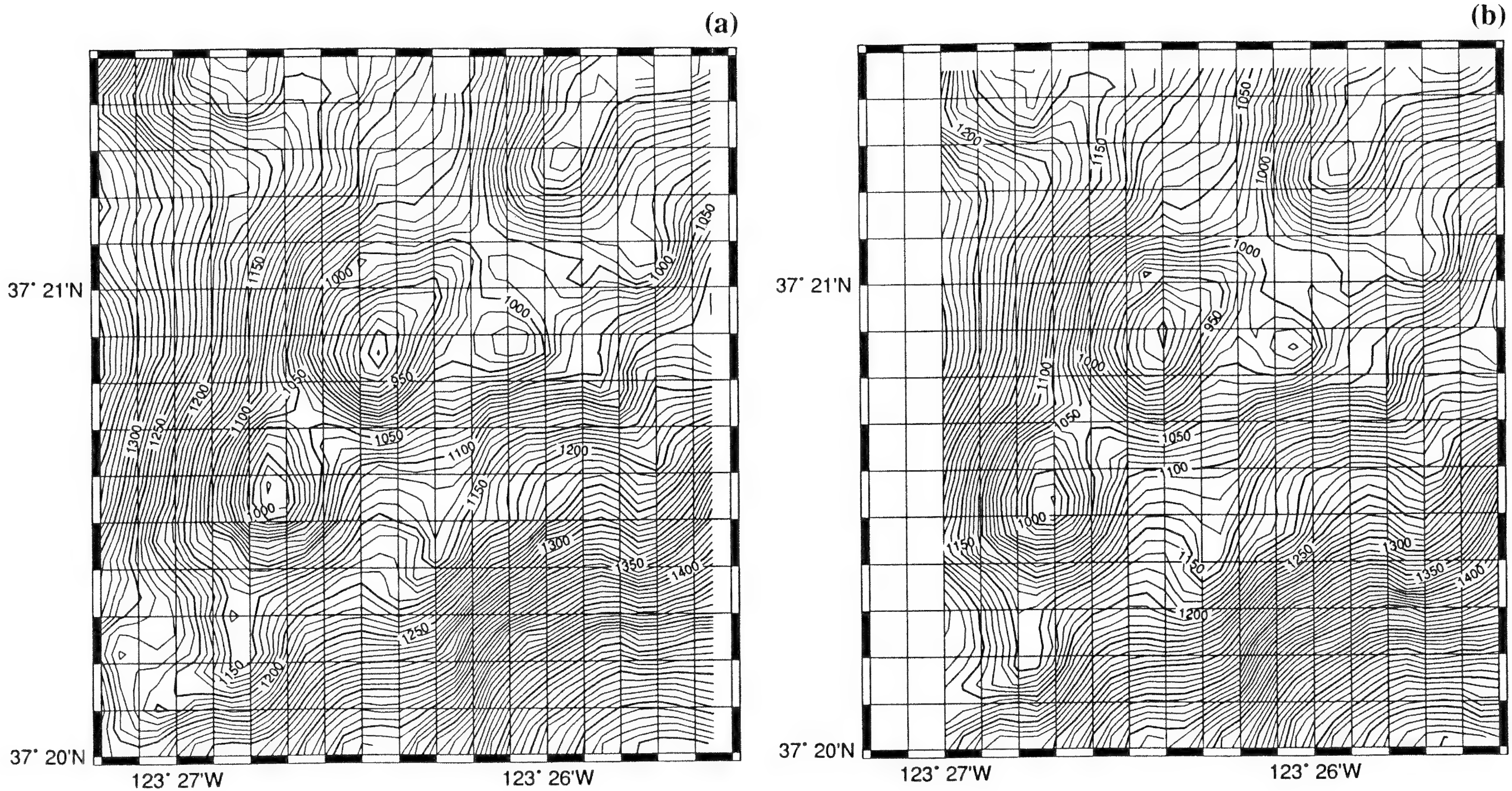


Figure 9. Bathymetry in the vicinity of the source site, as determined from data collected using the SeaBeam system on *Laney Chouest*. (a) First survey. (b) Second survey.

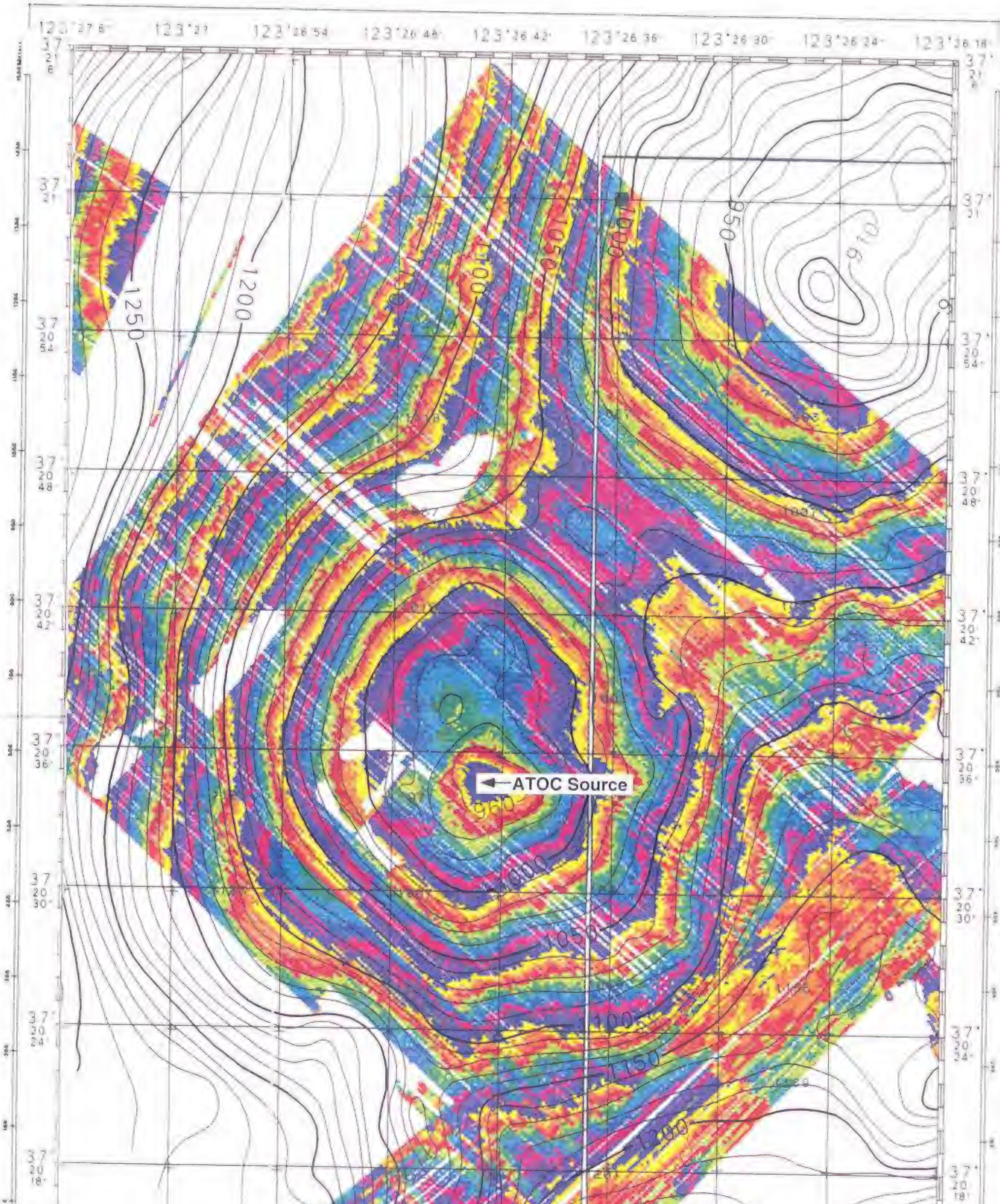


Figure 10. As in Figure 8, but for 120-kHz data with poor position accuracy. The lower left and upper right corners of the chart correspond to 37°20′12′′N, 123°27′6′′W and 37°21′6′′N, 123°26′18′′W, respectively. Grid lines are 6 seconds apart (600 ft, or 182 m, in latitude), the color interval is 5 m, and the contour interval is 10 m.

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Figure 11. Photograph of the bottom in the vicinity of the source site. The weight and tether to Transponder 1 can be seen in the right rear of the picture.

Figure 12. Photograph of rock recovered from Pioneer Seamount at 37°20.548′N, 123°26.709′W at a depth of 944 m during the ATOC source site survey by DSV 4 *Sea Cliff* on 14 October 1995.

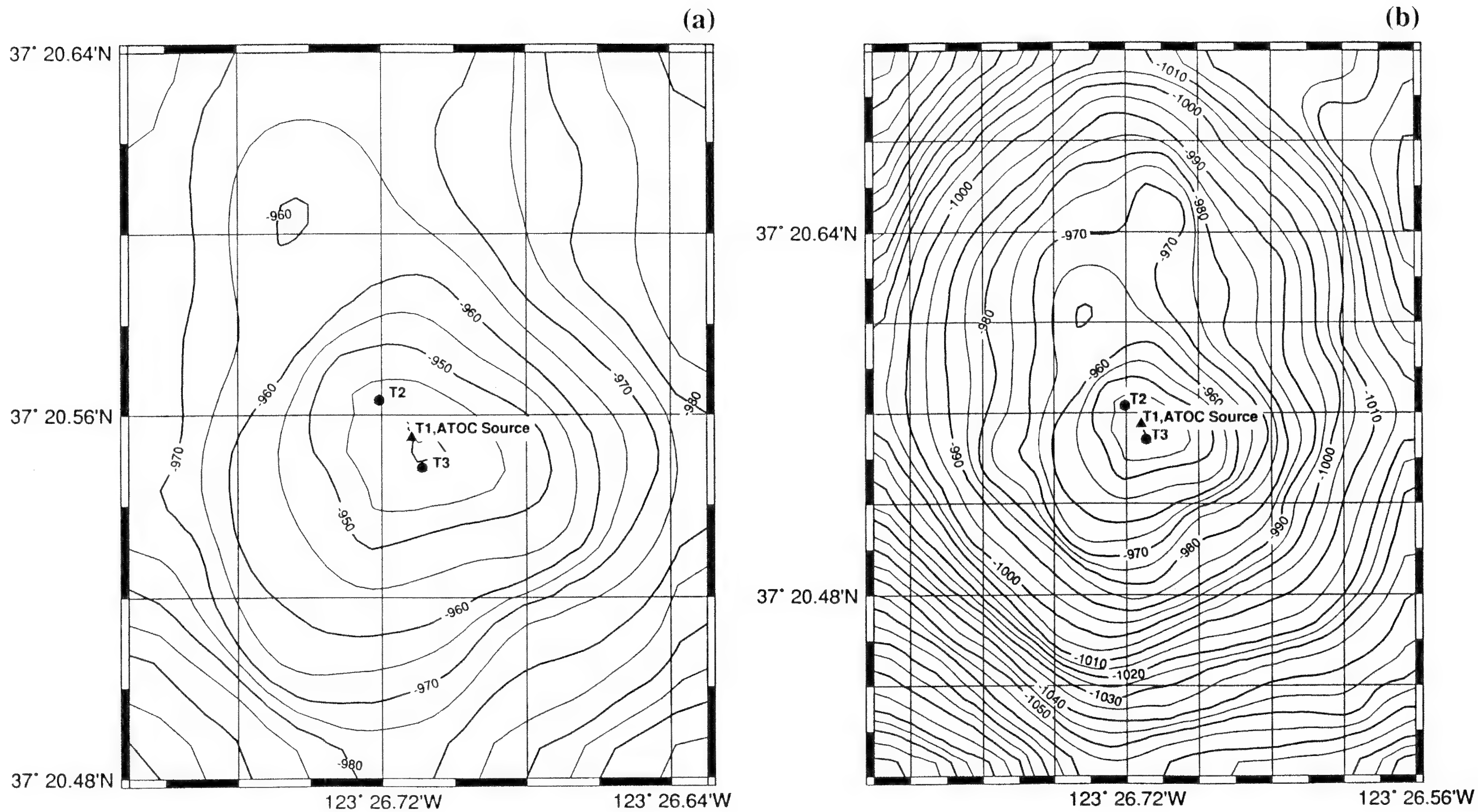


Figure 13. Charts showing the source and transponder locations. The bathymetry is from the 120-kHz data (Figure 10), shifted vertically to match the measured transponder depths and shifted horizontally so the absolute position of Transponder 1 (and the source Love Point) qualitatively matches the *Sea Cliff* observations of topography. Each grid box is 60 m by 74 m (east by north). (Machine-contouring artifacts are present at the middle of each edge.) (a) Just the peak of the seamount. (b) The peak including the flanks.

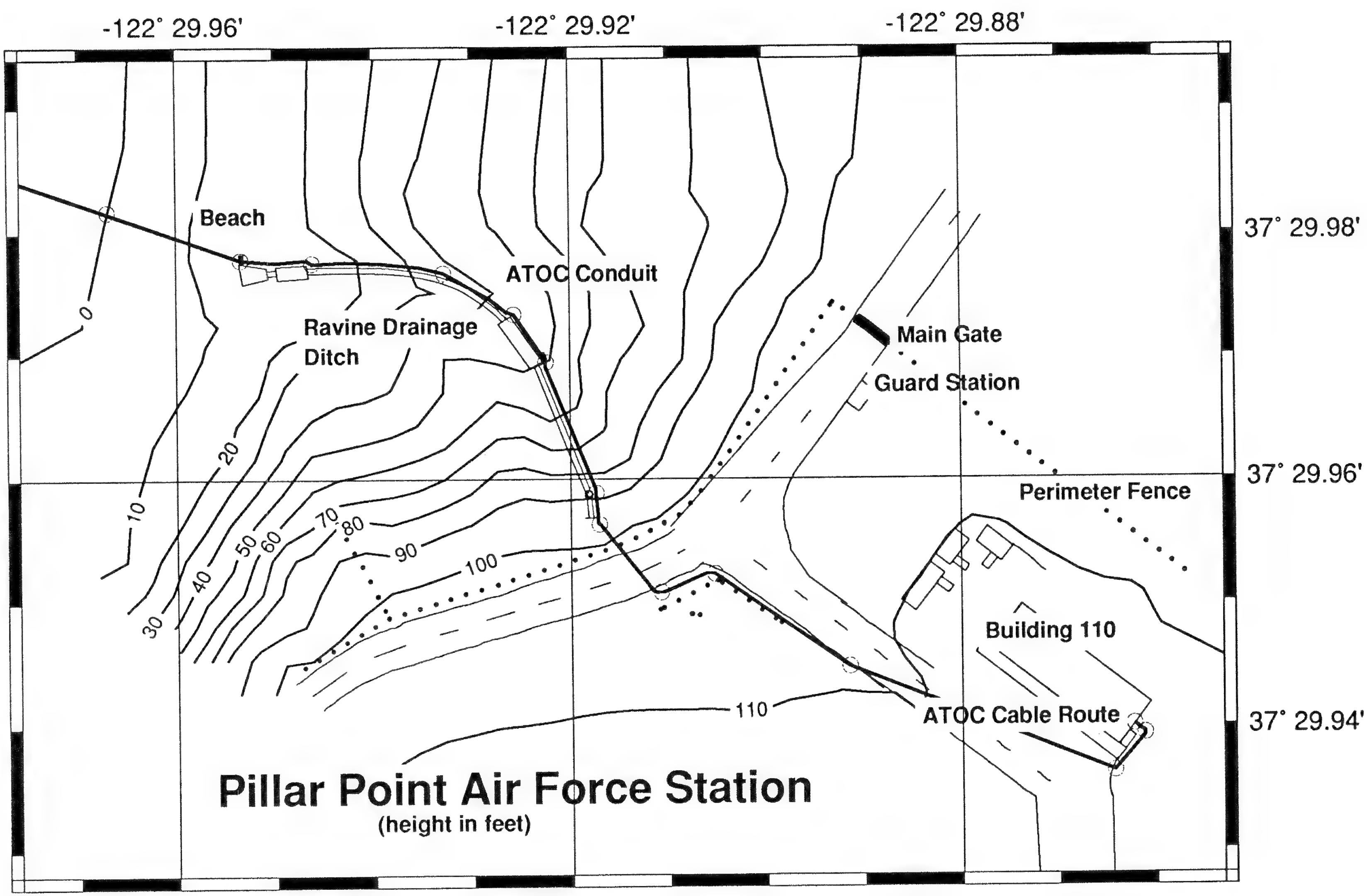


Figure 14. Map of the shore facility showing the cable route on land.

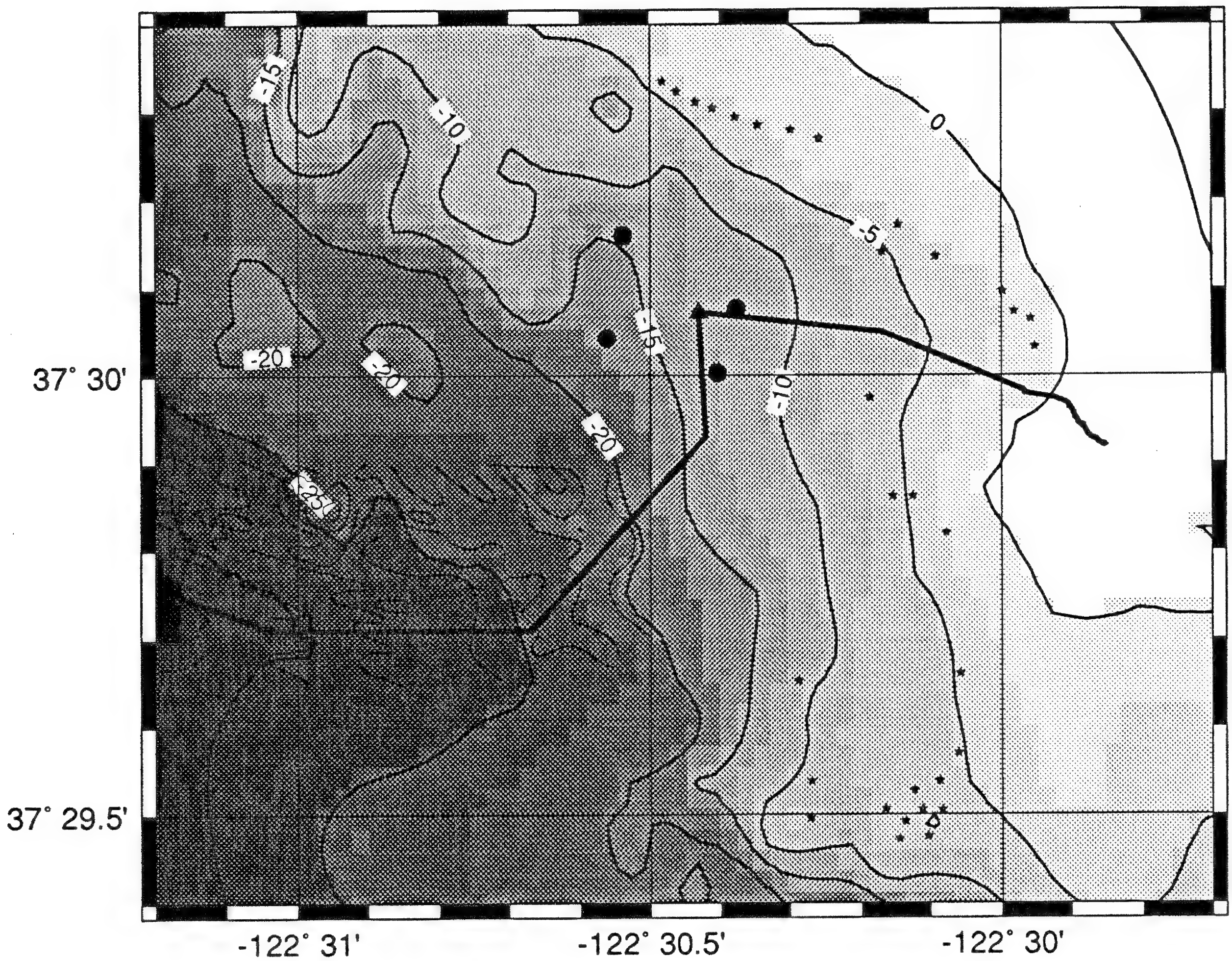


Figure 15. Chart showing the shore cable route and mooring positions.

(a) (b) (c) (d) (e)

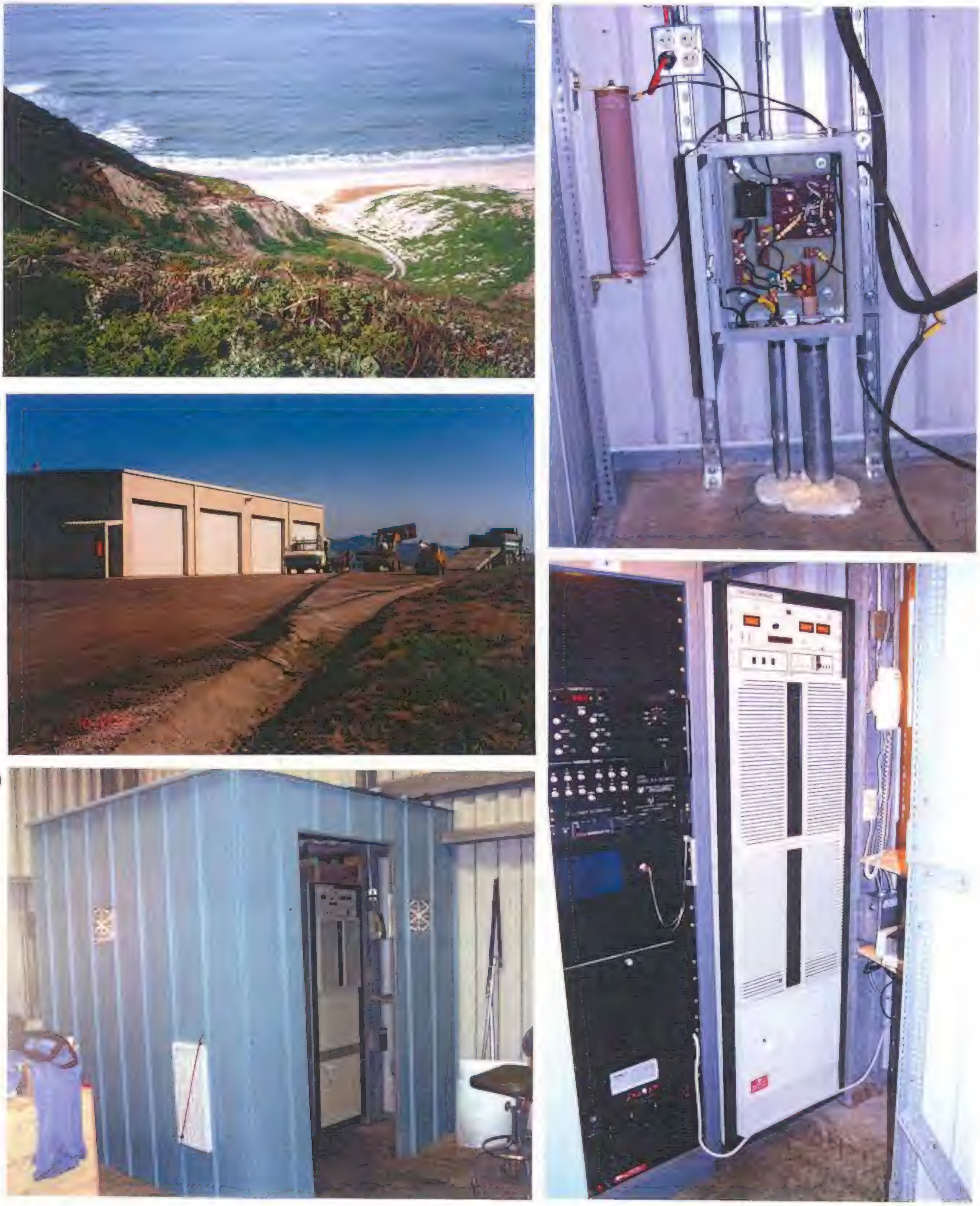


Figure 16. Photographs of the shore facility at Pillar Point. (a) Looking toward shore from the top of the hill; the cable path runs along the drainage ditch on the north (right) side. (b) Looking along the cable path from the top of the hill toward maintenance building 110. (c) ATOC equipment shelter. (d) Cable termination box. (e) Electronics/computer rack, on the left, and power amplifier, on the right.

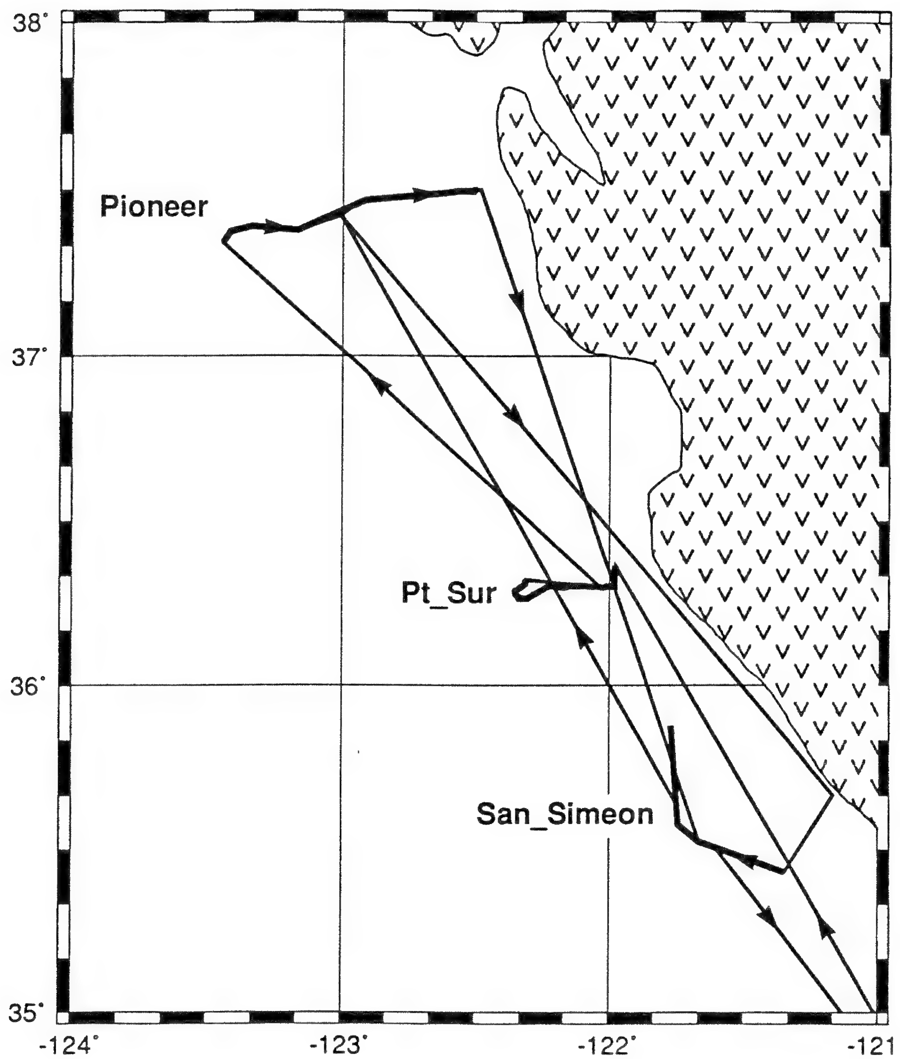


Figure 17. The *Independence* track for the entire cruise. (The digital shoreline used here is not very accurate.)

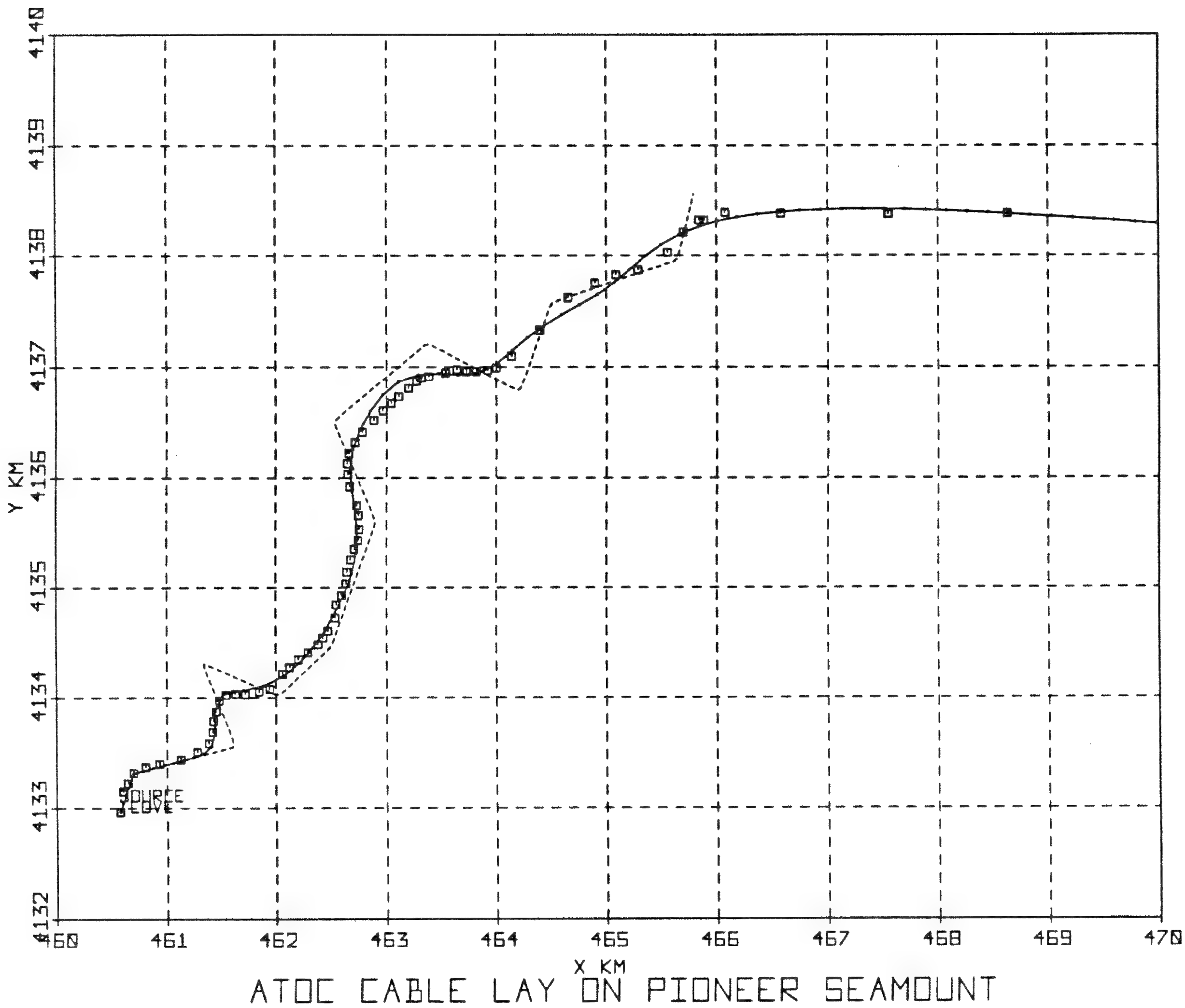
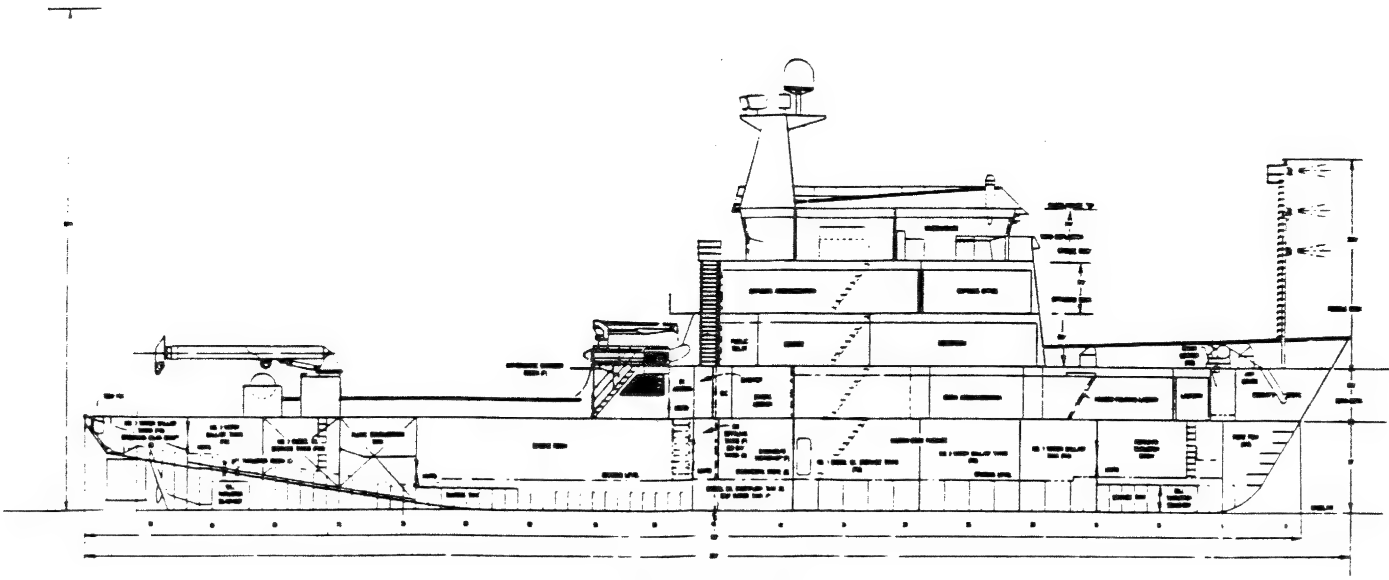


Figure 18. Modified ship route for cable laying on Pioneer Seamount based on cable dynamics (from McLennon, MariPro). The axes are UTM, Zone 10, easting and northing.



INBOARD PROFILE

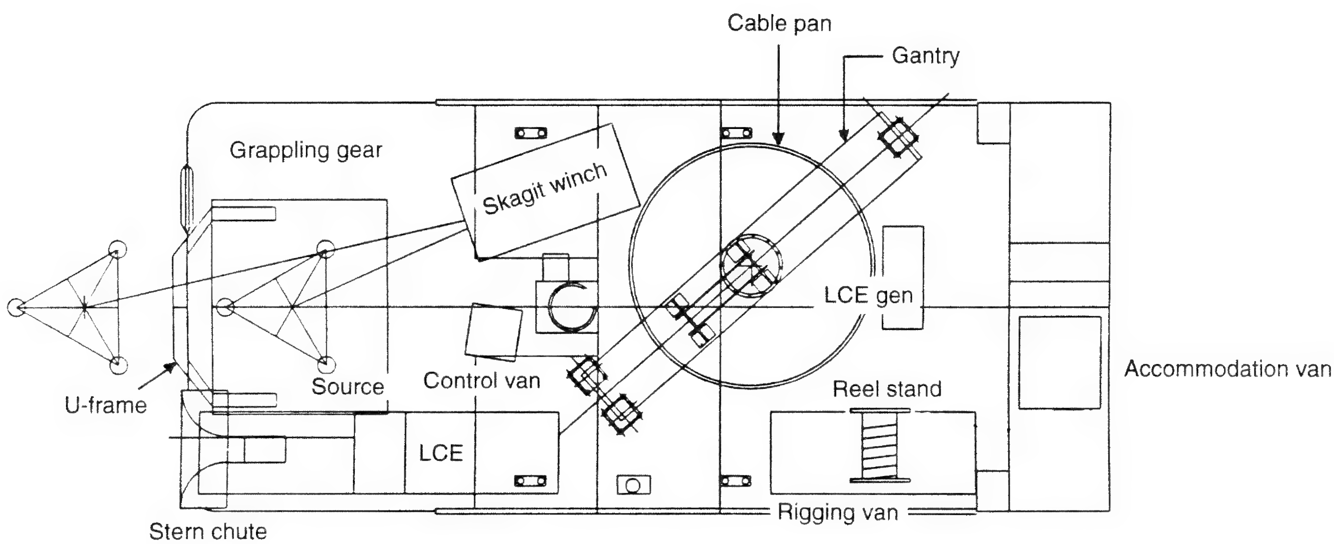


Figure 19. Deck layout. Also included are general ship's plans.

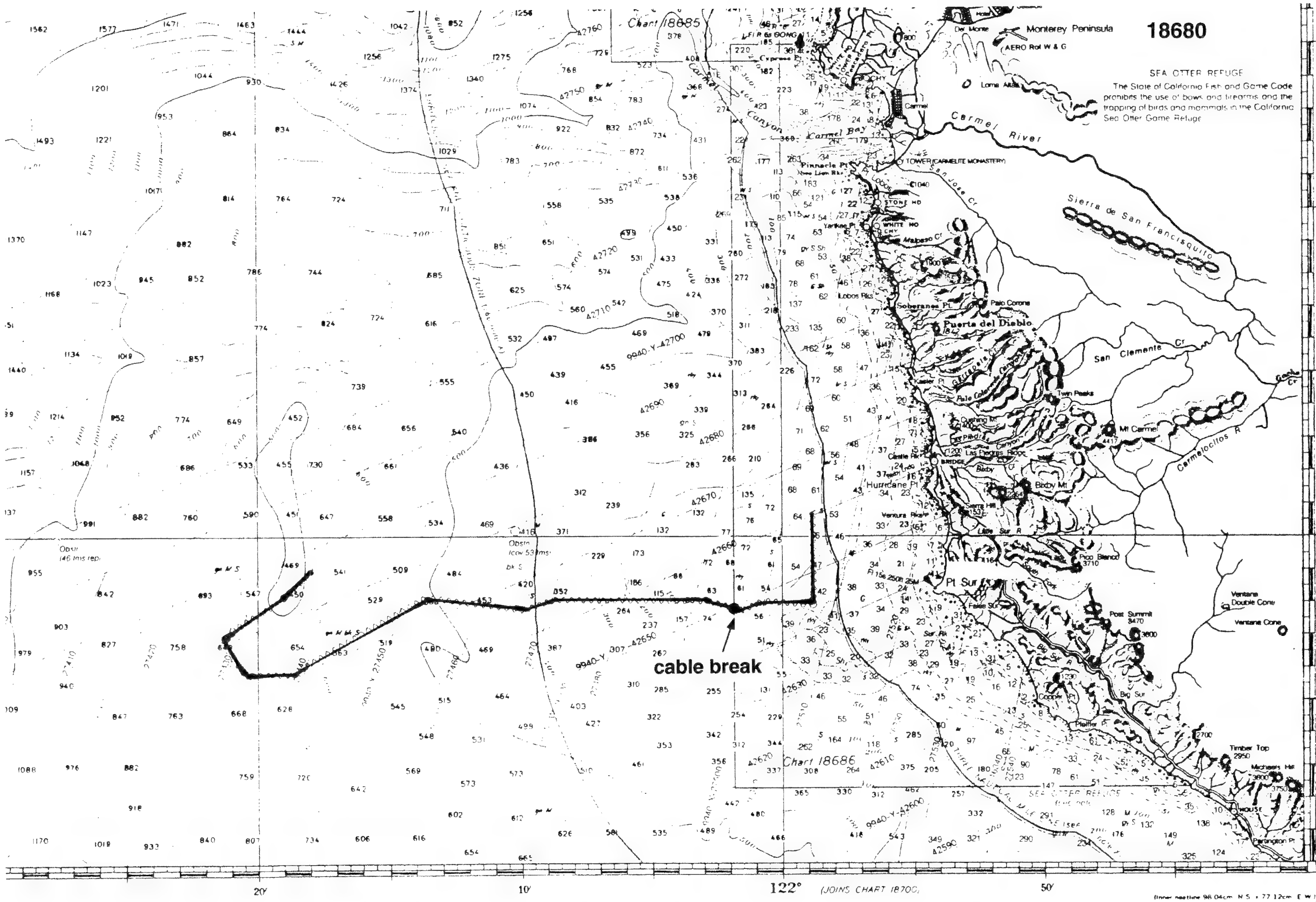


Figure 20. Point Sur cable route. The point the break was found is indicated.

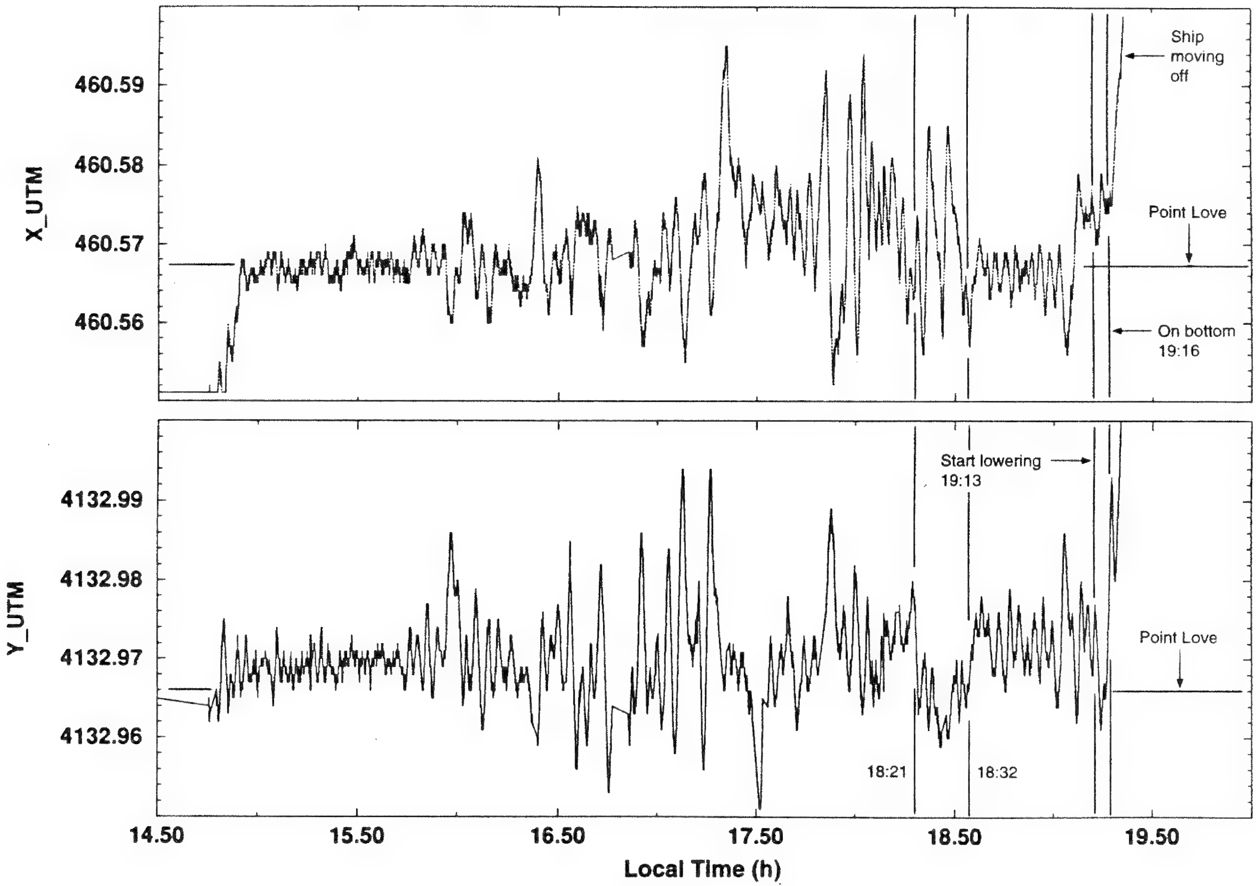


Figure 21. Plot of DGPS ship position data during deployment. The units of the ordinates are kilometers (each tick is 2 m; full scale is 50 m).

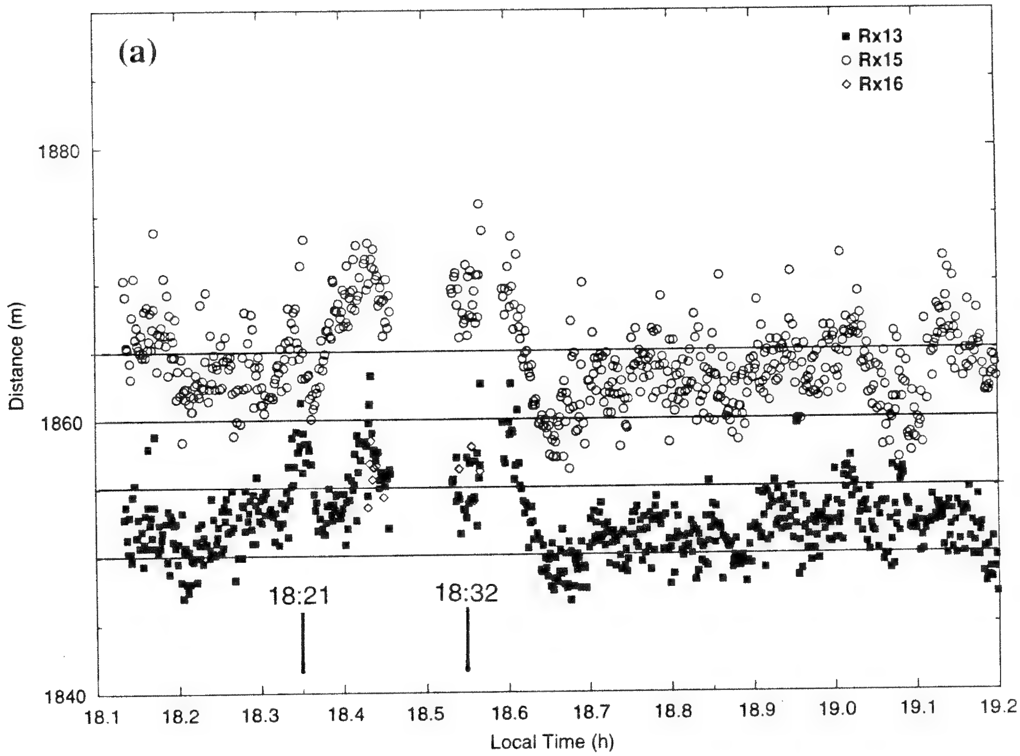


Figure 22a. Plots of acoustic tracking data: sing-around ranges prior to deployment (source at 914-m depth).

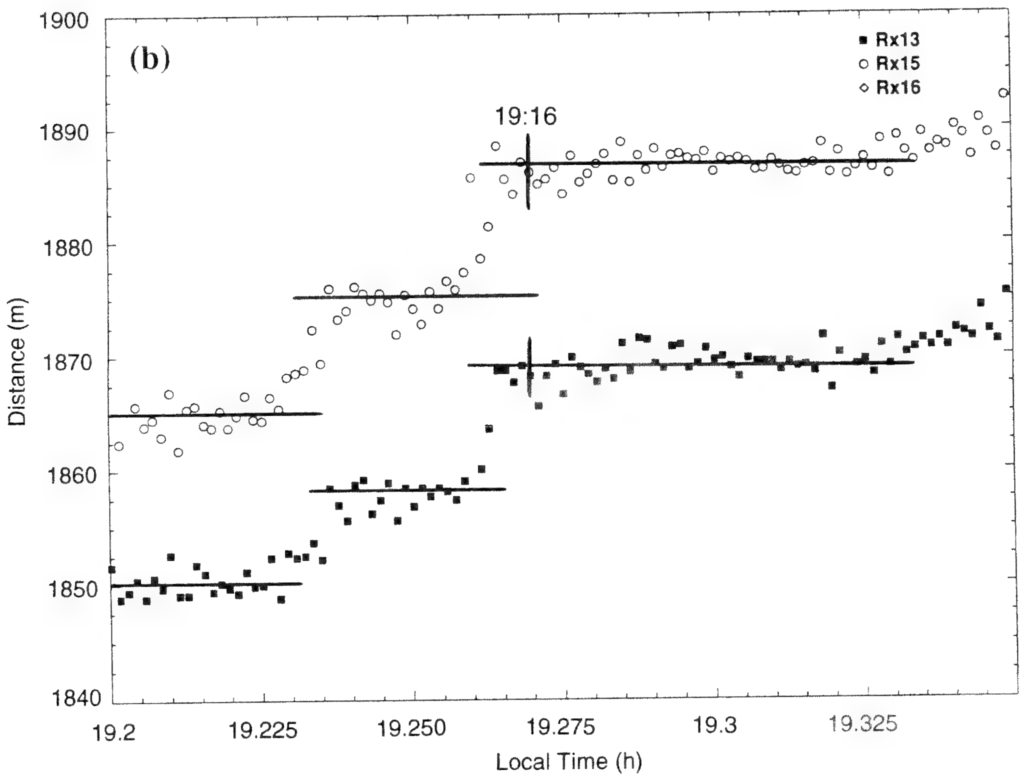


Figure 22b. Plots of acoustic tracking data: sing-around ranges during deployment.

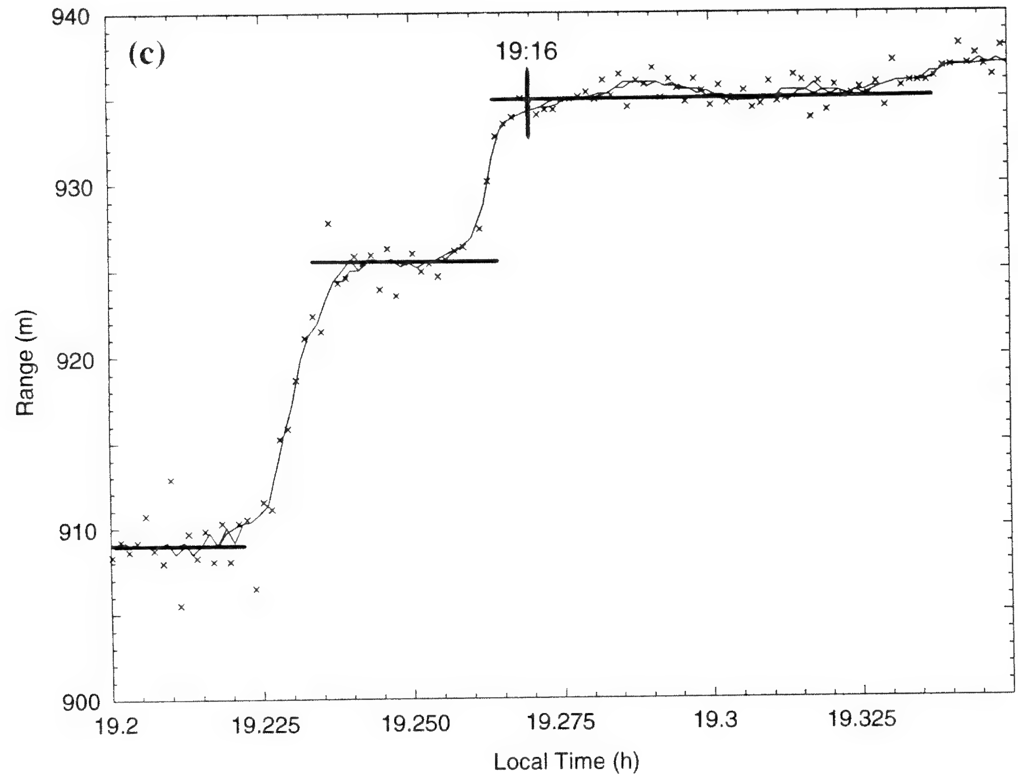


Figure 22c. Plots of acoustic tracking data: direct ranges from the ship to the source during deployment.

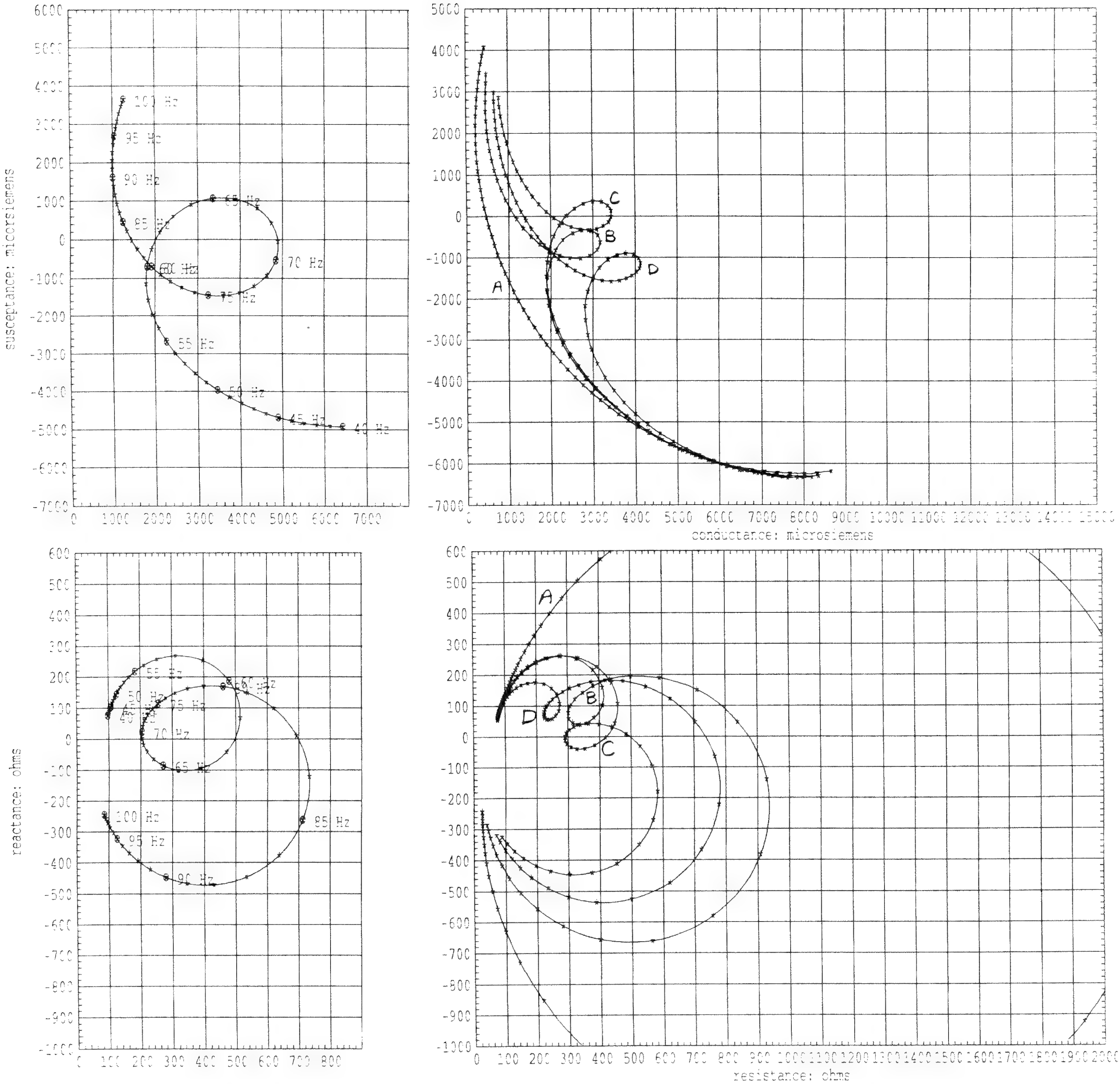


Figure 23. Plots of impedance (top) and admittance (bottom) as predicted based on Metzger's model (left) and as measured during pressurization of the source (right). Curves A, B, C, and D were measured at –4, 6, 13, and 22 minutes relative to turning on the gas at 1944 local time.

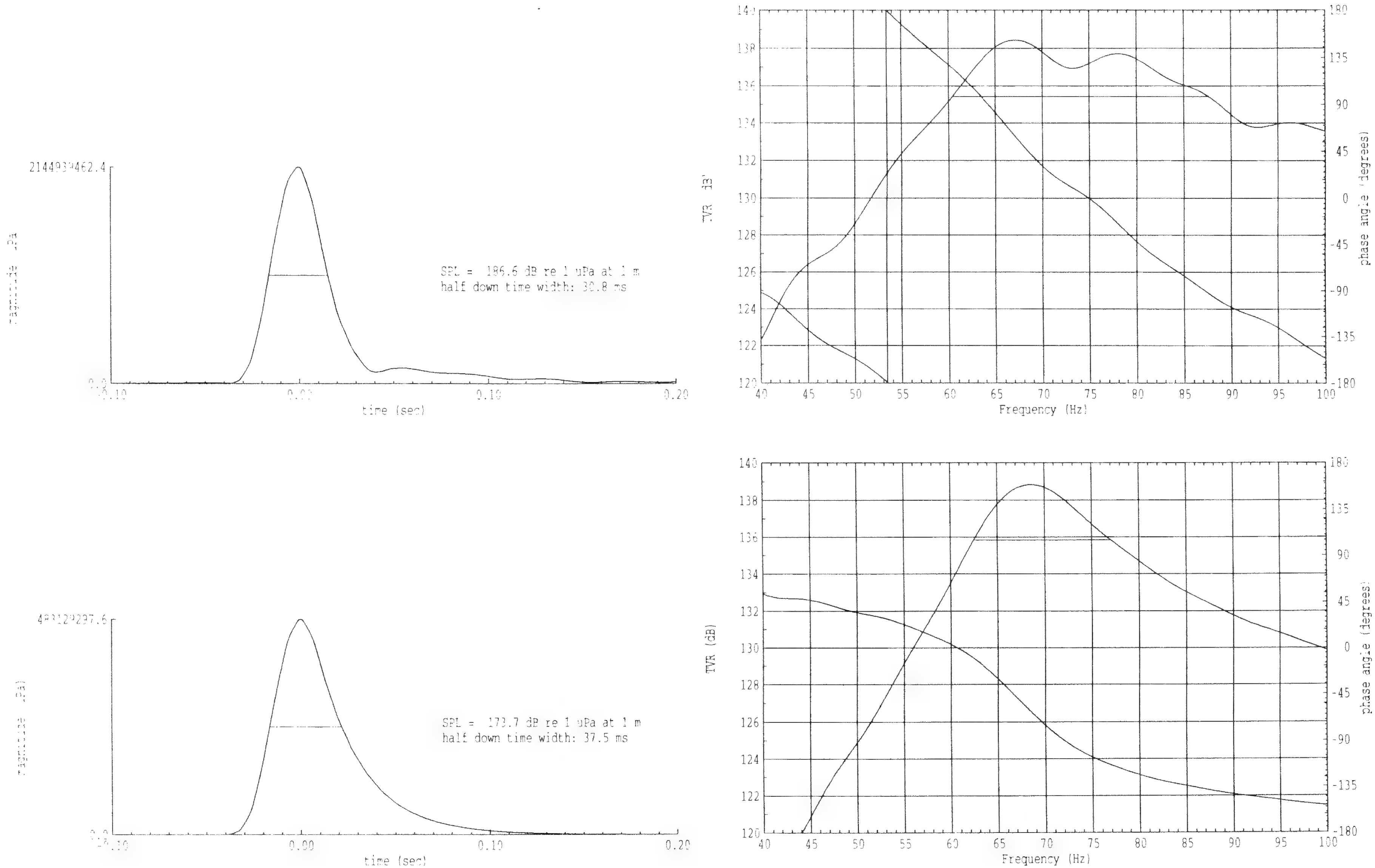


Figure 24. Acoustic reception of one of the first source transmissions. (a) Measured pulse, (b) measured spectrum, (c) modeled pulse, and (d) modeled spectrum.

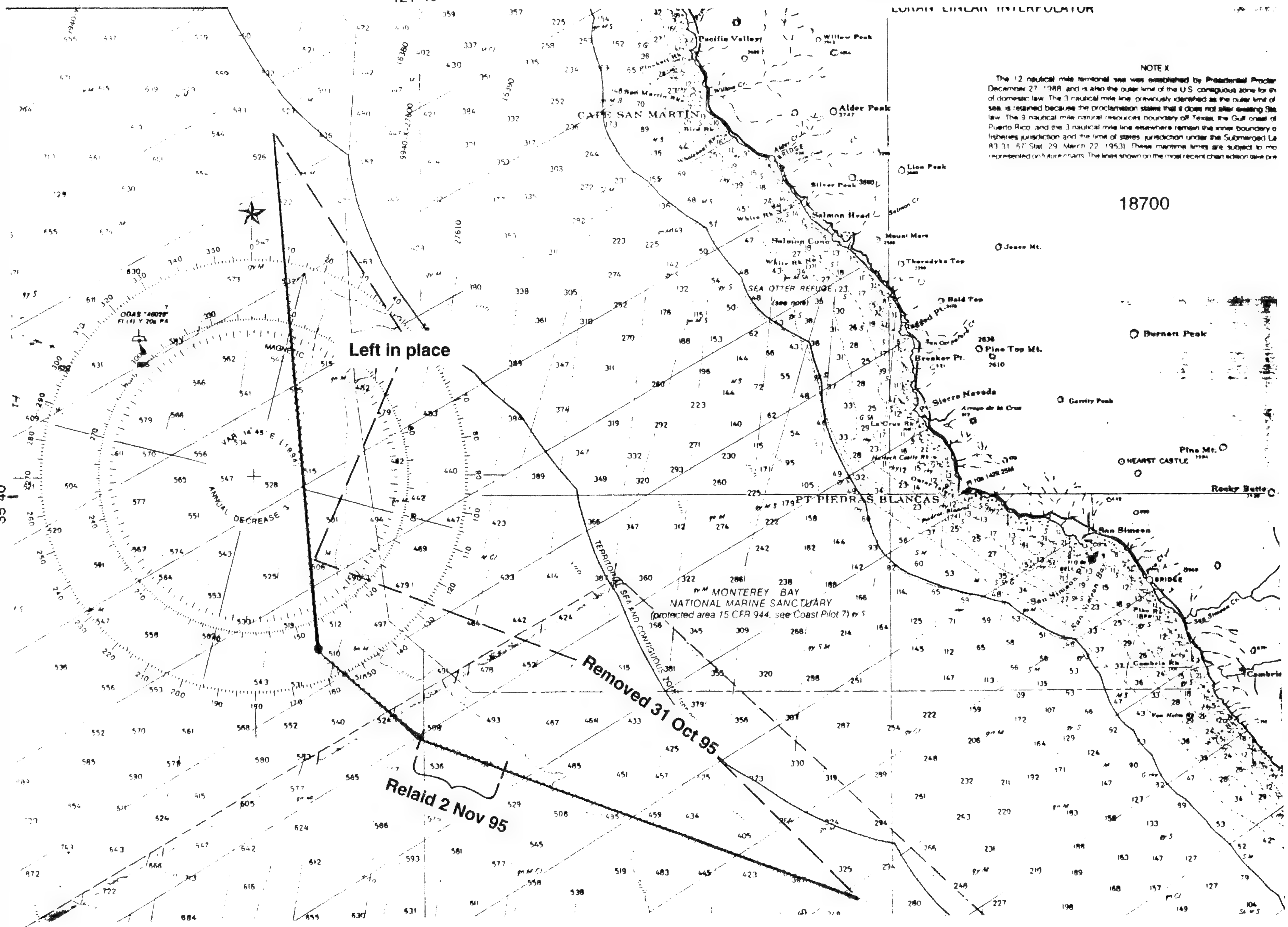
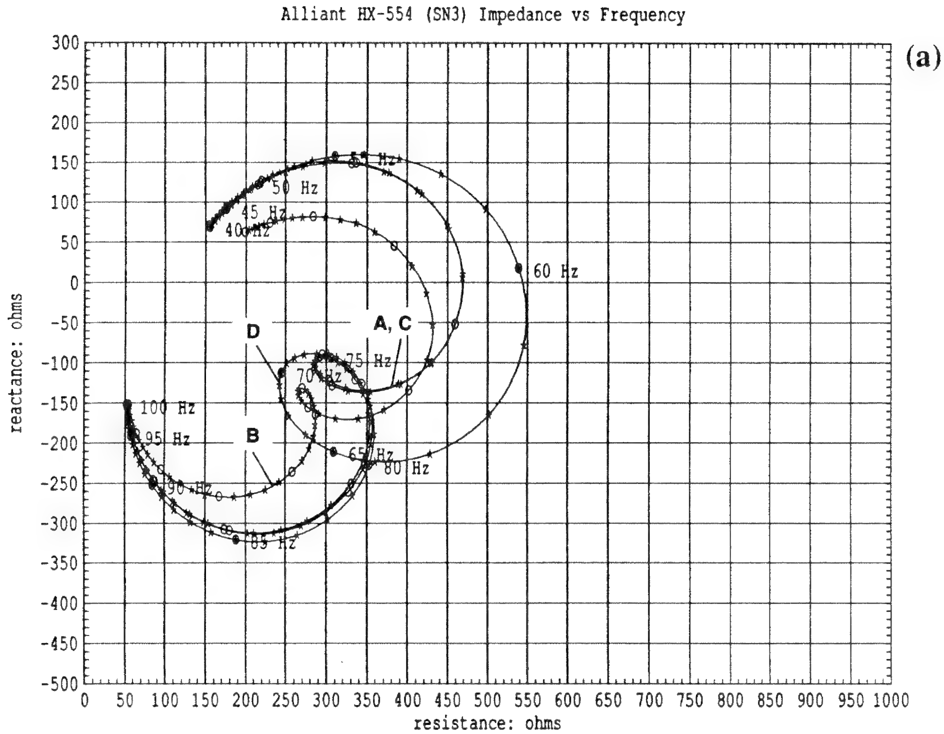


Figure 25. San Simeon cable route. The section removed is indicated, as is the 4.5-km-long section replaced at the end of the operation.



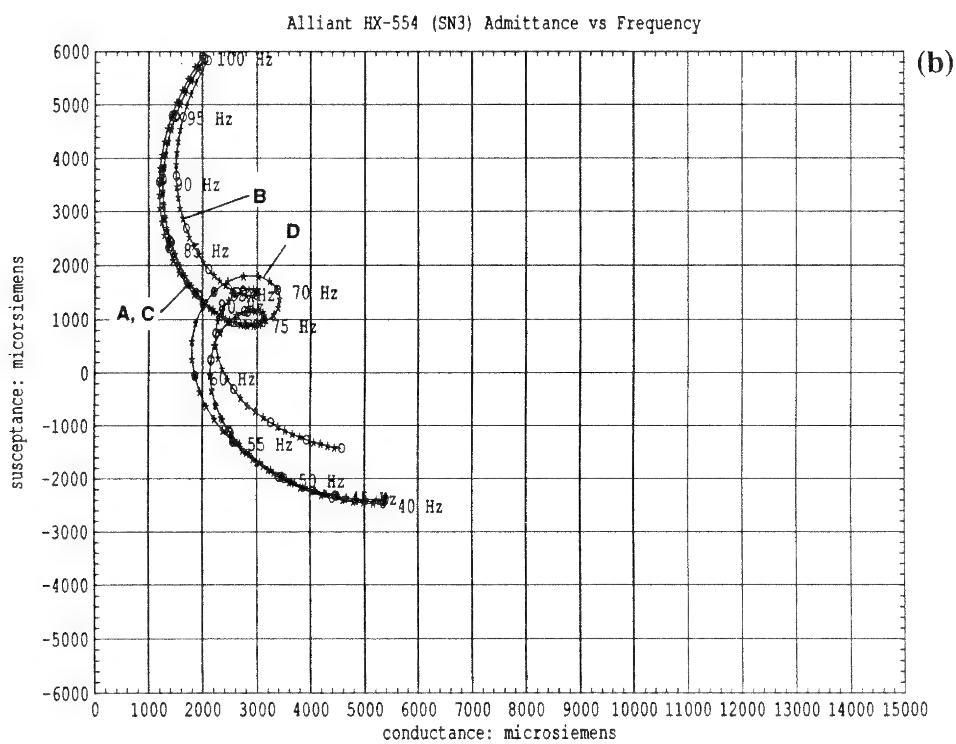


Figure 26. Plots of (a) source impedance and (b) source admittance at four times: A, 1200 UTC on 15 November 1995 (day 319); B, 0715 UTC on 22 November 1995 (day 326); C, 1200 UTC on 29 January 1996 (day 029); D, 1600 UTC on 1 February 1996 (day 032). Curve A is representative of the time following installation. Curve B is representative of the time when the source VLA was deteriorating. Curve C is representative of the time after the VLA was turned off and through 0800 UTC on 31 January 1996, and is nearly the same as curve A. Curve D is representative of the time after 1200 UTC on 31 January 1996.

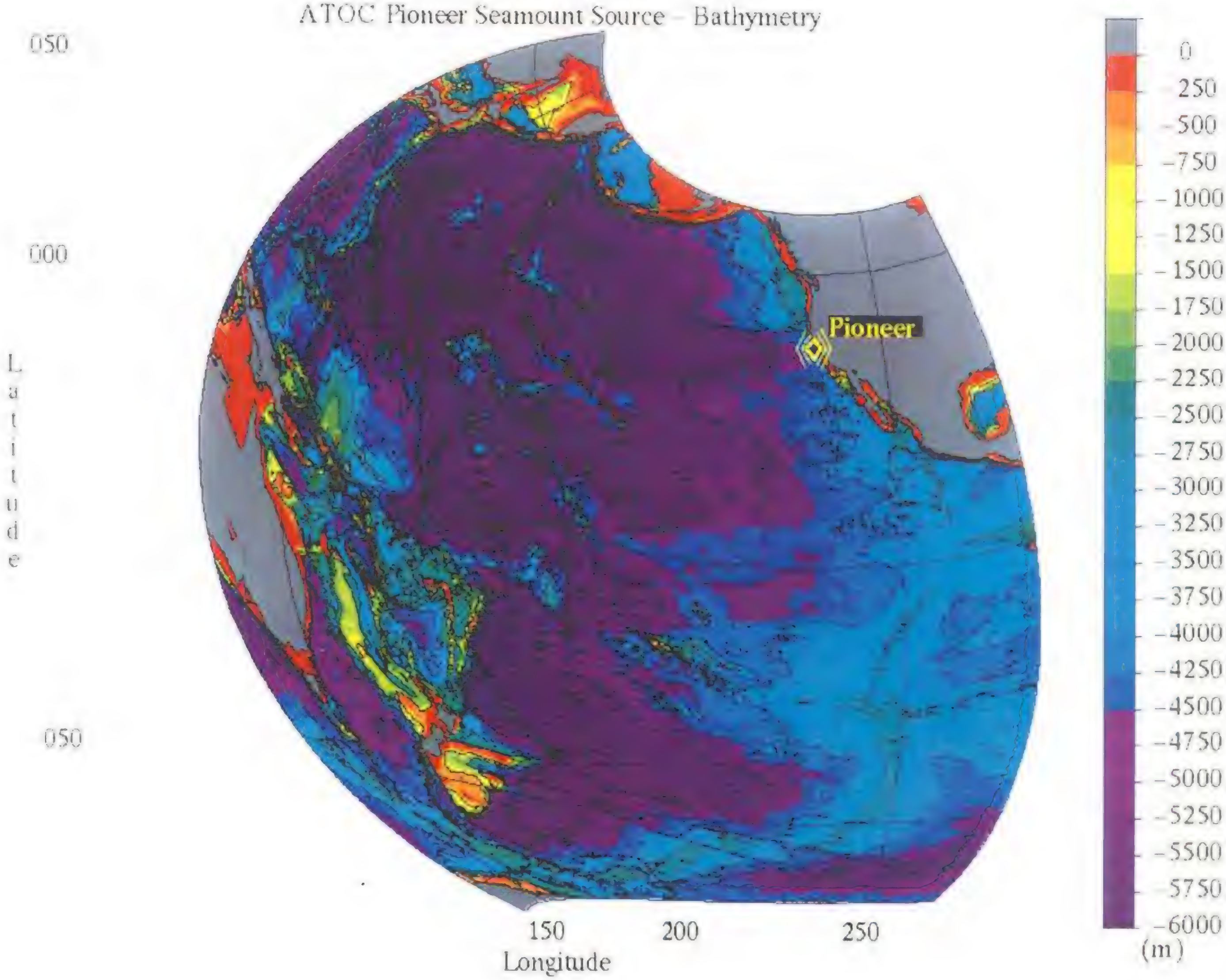


Figure 27. ETOP05 bathymetry of the Pacific Ocean. A Lambert azimuthal map projection is used with the origin at the Pioneer Seamount source location.

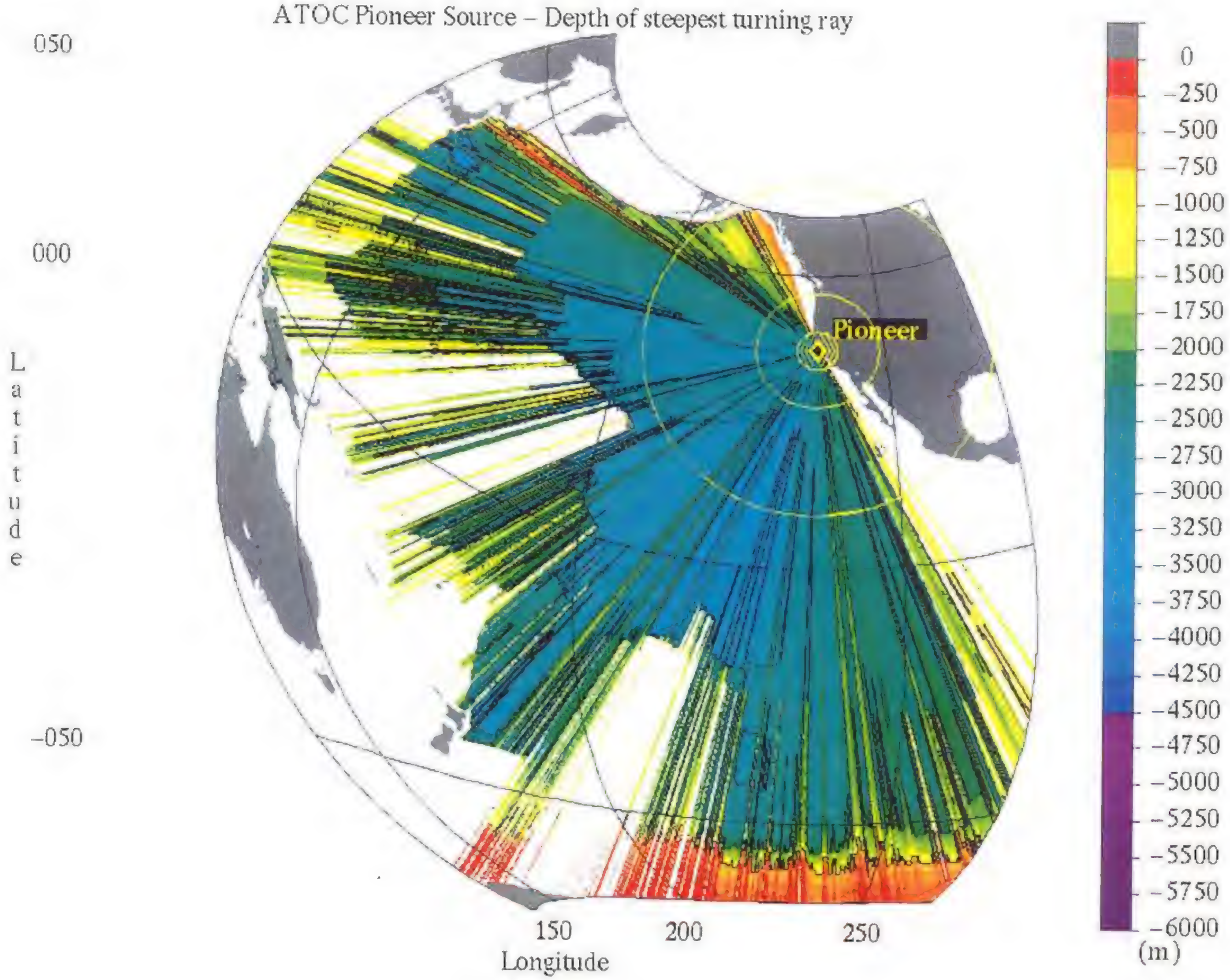


Figure 28. Shadow plot for the Pioneer Seamount source. The color indicates the depth of the lower turning point of the steepest nonbottom-interacting ray propagating away from the source.

Appendix A. Time Table

First *Laney Chouest* Cruise

27 Sep	1200			Depart Alameda for Pioneer Seamount
27 Sep	1700			Arrive Pioneer Seamount
28 Sep	0700			First Seabeam survey
29 Sep		-	2130	Second Seabeam survey
30 Sep	2300			Depart Pioneer Seamount
1 Oct	0400			Arrive Alameda

M/V *McGaw* Shore Cable Installation

25 Sep				Depart Santa Barbara for STC in Portland
28 Sep	1250			Arrive STC
29 Sep	0800	-	1340	Load armored cable
30 Sep	0710			Depart STC
3 Oct	1410			Arrive Pillar Point
4 Oct	0645		1400	Locate and deploy mooring anchors
5 Oct	0830			Moor the *McGaw*
5 Oct	0940		1345	Bring cable to shore
5 Oct	1600		1700	Pull cable up conduit
5 Oct	1710		1750	Sink cable
5 Oct	1900		1915	Unmoor
5 Oct	1917			Lay the cable
5 Oct		-	2345	Lower seaward-end with recovery package
6 Oct	0915	-	1205	Recover mooring anchors
6 Oct	1435			Depart for Santa Barbara
7 Oct	1730			Arrive Santa Barbara

Second *Laney Chouest* Cruise

13 Oct	1600			Depart Alameda for Pioneer Seamount
13 Oct	2000			Arrive Pioneer Seamount
14 Oct	0137			Deploy *Sea Cliff*
14 Oct	0300			*Sea Cliff* on bottom
14 Oct	0334			Deploy Transponder T1
14 Oct	0600			Deploy Transponder T2
14 Oct	0634			Deploy Transponder T3
14 Oct	0900			Begin ascent

14 Oct	1000	On surface
14 Oct	1100	Begin transponder survey
14 Oct	1400	Complete transponder survey
14 Oct	1500	Depart Pioneer Seamount
14 Oct	2000	Arrive Alameda

M/V *Independence* Source and Sea Cable Installation

23 Oct	2200	Dockside test deployment from the ship
24 Oct	0014	Depart for test site (10 nmi)
	0200	Test deploy source package, 5-m and 114-m tests
	0630	Depart for Point Sur (195 nmi)
25 Oct	0000	Arrive at east end of Point Sur cable
	0222	Release recovery line, recover cable end
		East end of cable on board
	1155	Damaged end on deck, proceed to west end of cable
	1400	Arrive west end of Point Sur cable, release recovery line
	1850	West end of cable on board
26 Oct		Recover cable, splice to eastern piece, repair gouges
	2330	Cut damaged cable, recover balance of damaged cable
27 Oct	0100	Depart for Pioneer Seamount (92 nmi)
	0925	Arrive at Pioneer Seamount, check transponders, rig source
	1326	Put source over the stern
	1429	At 114 m, test
	1718	At 922 m, test
	1900	Electrical fault detected
	2100	Recover source
28 Oct	0200	Source on board, make new cable termination/splice
	1353	Put source over the stern
	1435	At 114 m, test
	1705	At 896 m, test
	1720	At 906 m, test
	1718	At 916 m, test
	1916	Source touchdown, deploy short section of cable
	1944	Hold station, pressurize source and test
	2335	Begin cable lay
29 Oct	1725	End of cable section laid, deploy recovery package
	2100	Personnel transfer at Pillar Point
	2300	Depart for San Simeon
30 Oct	1000	Personnel transfer at San Simeon
	1130	Grapple for cable recovery line
	2100	End of cable on board, recover cable

31 Oct				Recover required cable length, deploy recovery line on remainder
	1800			Depart for end of source cable (127 nmi)
1 Nov	0500			Arrive at end of source cable
	0825			Source cable end on board, test
	0900	-	1320	Splice completed
	1500			Lay cable toward shore
	2200			Arrive at seaward end of shore cable
	2237			Recover shore cable end and test
2 Nov	0030	-	0530	Splice
	0635			Shore party tests source system
	0715			Bight deployed
	0830			Personnel transfer at Pillar Point
	1000			Depart for San Simeon
	2000			Deploy spare cable
3 Nov	0000			Depart for Port Hueneme
	1230			Arrive Port Hueneme

Times are local. (Note: Local time = UTC – 7 to 0000 29 October and UTC – 8 thereafter because of switching from Pacific Daylight Time to Pacific Standard Time. Also, 27 October = yearday 300.)

Appendix B. Pioneer Seamount Cable Route Coordinates

From: Pioneer Seamount

To: Pillar Point Shoreline

Posn No	Latitude DD MM.MMMM	Longitude DDD MM.MMMM	Heading (deg T)	Depth (m)	Horizontal Distance (km) Between Positions	Horizontal Distance (km) Cumulative Total	% Slack	Cable Length (km) Between Positions	Cable Length (km) Cumulative Total	Comments
1	37 20.5550N	123 26.7117W		941		0.000			0.000	Source
			10.69		0.185		5.0	0.203		
2	37 20.6533N	123 26.6884W		996		0.185			0.203	
			29.83		0.086		5.0	0.092		
3	37 20.6938N	123 26.6592W		1012		0.272			0.295	
			29.23		0.105		5.0	0.111		
4	37 20.7434N	123 26.6243W		1015		0.377			0.406	Saddle
			63.76		0.121		5.0	0.127		
5	37 20.7722N	123 26.5508W		1012		0.498			0.533	
			76.59		0.130		5.0	0.137		
6	37 20.7885N	123 26.4648W		1009		0.628			0.670	
			77.85		0.197		5.0	0.208		
7	37 20.8109N	123 26.3339W		992		0.825			0.878	
			65.90		0.169		5.0	0.177		
8	37 20.8481N	123 26.2294W		990		0.994			1.055	
			53.31		0.131		5.0	0.140		
9	37 20.8904N	123 26.1579W		968		1.125			1.195	
			19.29		0.108		5.0	0.114		
10	37 20.9455N	123 26.1337W		962		1.234			1.308	
			4.47		0.099		5.0	0.104		
11	37 20.9988N	123 26.1284W		967		1.333			1.412	
			13.16		0.088		5.0	0.093		
12	37 21.0453N	123 26.1148W		969		1.421			1.505	
			16.10		0.104		5.0	0.110		
13	37 21.0990N	123 26.0952W		985		1.525			1.616	
			48.74		0.081		5.0	0.085		
14	37 21.1277N	123 26.0541W		979		1.605			1.700	
			83.98		0.089		5.0	0.093		
15	37 21.1327N	123 25.9944W		975		1.694			1.793	
			93.58		0.090		5.0	0.095		
16	37 21.1297N	123 25.9332W		970		1.784			1.888	
			79.02		0.129		5.0	0.137		
17	37 21.1430N	123 25.8472W		950		1.913			2.026	
			74.98		0.095		5.0	0.100		
18	37 21.1562N	123 25.7849W		951		2.008			2.125	
			41.17		0.180		5.0	0.189		
19	37 21.2295N	123 25.7043W		945		2.189			2.315	
			45.67		0.089		5.0	0.094		
20	37 21.2629N	123 25.6613W		956		2.277			2.409	
			47.63		0.110		5.0	0.115		
21	37 21.3027N	123 25.6064W		946		2.387			2.524	
			53.03		0.103		5.0	0.109		
22	37 21.3361N	123 25.5505W		933		2.490			2.633	
			51.01		0.118		5.0	0.124		
23	37 21.3762N	123 25.4883W		939		2.608			2.757	
			35.89		0.076		5.0	0.080		
24	37 21.4094N	123 25.4581W		935		2.684			2.837	
			36.71		0.077		5.0	0.081		
25	37 21.4426N	123 25.4269W		935		2.760			2.917	
			27.18		0.139		5.0	0.146		
26	37 21.5092N	123 25.3839W		936		2.899			3.063	
			4.71		0.120		5.0	0.126		
27	37 21.5738N	123 25.3772W		933		3.019			3.189	
			29.81		0.097		5.0	0.102		
28	37 21.6192N	123 25.3445W		931		3.116			3.291	
			20.10		0.115		5.0	0.121		
29	37 21.6777N	123 25.3175W		926		3.232			3.413	
			4.42		0.106		5.0	0.112		
30	37 21.7349N	123 25.3120W		927		3.338			3.524	
			16.25		0.119		5.0	0.125		

ATOC Cable Route

From: Pioneer Seamount

To: Pillar Point Shoreline

Posn No	Latitude DD MM.MMMM	Longitude DDD MM.MMMM	Heading (deg T)	Depth (m)	Horizontal Distance (km) Between Positions	Horizontal Distance (km) Cumulative Total	% Slack	Cable Length (km) Between Positions	Cable Length (km) Cumulative Total	Comments
31	37 21.7963N	123 25.2895W		936		3.457			3.649	
			19.25		0.101		5.0	0.106		
32	37 21.8475N	123 25.2670W		938		3.557			3.755	
			22.98		0.088		5.0	0.093		
33	37 21.8912N	123 25.2437W		930		3.645			3.847	
			3.90		0.102		5.0	0.107		
34	37 21.9461N	123 25.2389W		922		3.747			3.955	
			357.67		0.127		5.0	0.134		
35	37 22.0147N	123 25.2425W		932		3.874			4.089	
			349.15		0.091		5.0	0.096		
36	37 22.0631N	123 25.2541W		934		3.966			4.185	
			339.79		0.184		5.0	0.193		
37	37 22.1563N	123 25.2973W		933		4.150			4.378	
			350.45		0.112		5.0	0.118		
38	37 22.2160N	123 25.3099W		930		4.262			4.496	
			356.31		0.096		5.0	0.101		
39	37 22.2676N	123 25.3141W		926		4.358			4.597	
			8.99		0.095		5.0	0.100		
40	37 22.3185N	123 25.3040W		920		4.453			4.697	
			29.27		0.112		5.0	0.118		
41	37 22.3712N	123 25.2668W		910		4.565			4.815	
			34.80		0.113		5.0	0.120		
42	37 22.4215N	123 25.2229W		900		4.679			4.935	
			44.42		0.148		5.0	0.158		
43	37 22.4785N	123 25.1525W		873		4.827			5.093	
			43.32		0.119		5.0	0.126		
44	37 22.5254N	123 25.0970W		863		4.946			5.218	NE_Peak
			48.28		0.104		5.0	0.109		
45	37 22.5627N	123 25.0443W		867		5.050			5.327	
			47.77		0.091		5.0	0.097		
46	37 22.5956N	123 24.9987W		884		5.141			5.424	
			49.11		0.118		5.0	0.127		
47	37 22.6373N	123 24.9381W		910		5.259			5.551	
			48.71		0.096		5.0	0.103		
48	37 22.6714N	123 24.8892W		931		5.355			5.654	
			58.16		0.053		5.0	0.056		
49	37 22.6866N	123 24.8584W		937		5.408			5.711	
			76.57		0.065		5.0	0.068		
50	37 22.6948N	123 24.8154W		938		5.473			5.779	
			77.60		0.156		5.0	0.172		
51	37 22.7129N	123 24.7119W		990		5.629			5.952	
			73.18		0.108		5.0	0.117		
52	37 22.7298N	123 24.6414W		1016		5.737			6.069	
			101.49		0.089		5.0	0.096		
53	37 22.7202N	123 24.5819W		1035		5.827			6.165	
			90.00		0.092		5.0	0.098		
54	37 22.7202N	123 24.5197W		1055		5.919			6.263	
			82.59		0.102		5.0	0.110		
55	37 22.7273N	123 24.4510W		1076		6.021			6.373	
			74.47		0.084		5.0	0.090		
56	37 22.7394N	123 24.3961W		1095		6.104			6.463	
			52.88		0.171		5.0	0.188		
57	37 22.7950N	123 24.3036W		1150		6.275			6.651	
			47.18		0.348		5.0	0.382		
58	37 22.9230N	123 24.1306W		1255		6.623			7.033	
			41.40		0.388		5.0	0.416		
59	37 23.0804N	123 23.9566W		1335		7.012			7.450	
			62.07		0.276		5.0	0.295		
60	37 23.1503N	123 23.7909W		1384		7.288			7.744	
			67.50		0.203		5.0	0.218		

ATOC Cable Route

From: Pioneer Seamount | To: Pillar Point Shoreline

Posn No	Latitude DD MM.MMMM	Longitude DDD MM.MMMM	Heading (deg T)	Depth (m)	Horizontal Distance (km) Between Positions	Horizontal Distance (km) Cumulative Total	% Slack	Cable Length (km) Between Positions	Cable Length (km) Cumulative Total	Comments
61	37 23.1921N	123 23.6636W		1430		7.491			7.962	
			77.35		0.207		5.0	0.225		
62	37 23.2166N	123 23.5263W		1486		7.698			8.188	
			59.05		0.310		5.0	0.332		
63	37 23.3029N	123 23.3459W		1548		8.008			8.520	
			38.21		0.233		5.0	0.255		
64	37 23.4018N	123 23.2480W		1617		8.242			8.775	
			51.22		0.178		5.0	0.197		
65	37 23.4620N	123 23.1537W		1676		8.420			8.972	
			90.00		0.047		5.0	0.050		
66	37 23.4620N	123 23.1216W		1683		8.467			9.023	
			69.34		0.203		5.0	0.224		
67	37 23.5007N	123 22.9926W		1748		8.670			9.247	
			90.91		0.505		5.0	0.537		
68	37 23.4963N	123 22.6501W		1825		9.175			9.783	
			90.00		0.969		5.0	1.018		
69	37 23.4963N	123 21.9937W		1861		10.144			10.801	
			89.58		1.089		5.0	1.144		
70	37 23.5007N	123 21.2558W		1873		11.233			11.945	
			92.39		1.494		5.0	1.569		
71	37 23.4670N	123 20.2441W		1874		12.728			13.514	Deep
			94.86		15.174		5.0	15.962		
72	37 22.7800N	123 10.0000W		944		27.901			29.476	
			66.00		11.310		5.0	11.880		
73	37 25.2700N	123 3.0000W		632		39.212			41.356	
			52.14		0.934		5.0	0.982		
74	37 25.5800N	123 2.5000W		601		40.146			42.338	swale
			65.17		0.683		5.0	0.717		
75	37 25.7350N	123 2.0800W		584		40.829			43.055	swale
			98.06		0.462		5.0	0.485		
76	37 25.7000N	123 1.7700W		563		41.290			43.540	
			106.54		2.087		5.0	2.192		
77	37 25.3790N	123 0.4140W		513		43.377			45.732	Splice
			53.56		6.260		5.0	6.580		
78	37 27.3900N	122 57.0000W		242		49.638			52.312	
			64.23		3.275		5.0	3.440		
79	37 28.1600N	122 55.0000W		142		52.912			55.752	
			84.63		17.770		5.0	18.659		
80	37 29.0700N	122 43.0000W		77		70.683			74.411	
			85.59		6.461		5.0	6.784		
81	37 29.3400N	122 38.6300W		66		77.143			81.195	
			85.25		2.899		5.0	3.044		
82	37 29.4700N	122 36.6700W		61		80.042			84.239	
			81.22		4.474		5.0	4.698		
83	37 29.8400N	122 33.6700W		48		84.517			88.937	
			87.81		0.774		5.0	0.813		
84	37 29.8560N	122 33.1450W		46		85.291			89.750	Splice
			90.69		2.498		1.0	2.523		
85	37 29.8400N	122 31.4500W		34		87.789			92.273	
			111.70		0.650		1.0	0.657		
86	37 29.7100N	122 31.0400W		30		88.440			92.930	Rock
			90.00		0.545		1.0	0.551		
87	37 29.7100N	122 30.6700W		24		88.985			93.481	Rock
			42.16		0.549		1.0	0.555		
88	37 29.9300N	122 30.4200W		14		89.534			94.035	
			356.82		0.265		1.0	0.268		
89	37 30.0730N	122 30.4300W		13		89.799			94.303	Moor
			96.34		0.386		1.0	0.389		
90	37 30.0500N	122 30.1700W		6		90.185			94.693	
			112.89		0.325		1.0	0.328		
91	37 29.9817N	122 29.9670W		0		90.510			95.021	Shoreline

ATOC Cable Route - Abbreviated

From: Pioneer Seamount To: Pillar Point Shoreline

Posn No	Latitude DD MM.MMMM	Longitude DDD MM.MMMM	Heading (deg T)	Depth (m)	Horizontal Distance (km) Between Positions	Horizontal Distance (km) Cumulative Total	% Slack	Cable Length (km) Between Positions	Cable Length (km) Cumulative Total	Comments
1	37 20.5550N	123 26.7117W		941		0.000			0.000	Source
			20.33		0.372		5.0	0.398		
2	37 20.7434N	123 26.6243W		1015		0.372			0.398	Saddle
			34.39		3.994		5.0	4.196		
3	37 22.5254N	123 25.0970W		863		4.365			4.594	NE_Peak
			59.86		3.592		5.0	3.884		
4	37 23.5007N	123 22.9926W		1748		7.957			8.479	
			90.89		4.057		5.0	4.262		
5	37 23.4670N	123 20.2441W		1874		12.014			12.741	Deep
			94.86		15.174		5.0	15.962		
6	37 22.7800N	123 10.0000W		944		27.188			28.703	
			66.00		11.310		5.0	11.880		
7	37 25.2700N	123 3.0000W		632		38.498			40.583	
			52.14		0.934		5.0	0.982		
8	37 25.5800N	123 2.5000W		601		39.432			41.565	swale
			65.17		0.683		5.0	0.717		
9	37 25.7350N	123 2.0800W		584		40.115			42.282	swale
			98.06		0.462		5.0	0.485		
10	37 25.7000N	123 1.7700W		563		40.577			42.767	
			106.54		2.087		5.0	2.192		
11	37 25.3790N	123 0.4140W		513		42.664			44.959	Splice
			53.56		6.260		5.0	6.580		
12	37 27.3900N	122 57.0000W		242		48.924			51.538	
			64.23		3.275		5.0	3.440		
13	37 28.1600N	122 55.0000W		142		52.199			54.979	
			84.63		17.770		5.0	18.659		
14	37 29.0700N	122 43.0000W		77		69.969			73.637	
			85.59		6.461		5.0	6.784		
15	37 29.3400N	122 38.6300W		66		76.430			80.421	
			85.25		2.899		5.0	3.044		
16	37 29.4700N	122 36.6700W		61		79.329			83.465	
			81.22		4.474		5.0	4.698		
17	37 29.8400N	122 33.6700W		48		83.803			88.163	Splice
			87.81		0.774		5.0	0.813		
18	37 29.8560N	122 33.1450W		46		84.577			88.976	
			90.69		2.498		1.0	2.523		
19	37 29.8400N	122 31.4500W		34		87.076			91.499	Rock
			111.70		0.650		1.0	0.657		
20	37 29.7100N	122 31.0400W		30		87.726			92.156	Rock
			90.00		0.545		1.0	0.551		
21	37 29.7100N	122 30.6700W		24		88.271			92.707	
			42.16		0.549		1.0	0.555		
22	37 29.9300N	122 30.4200W		14		88.820			93.262	Moor
			356.82		0.265		1.0	0.268		
23	37 30.0730N	122 30.4300W		13		89.086			93.530	
			96.34		0.386		1.0	0.389		
24	37 30.0500N	122 30.1700W		6		89.471			93.919	Shoreline

ATOC Cable Route

From: Pillar Point AFS - Building 110 To: shoreline

Posn No	Latitude DD MM.MMMM	Longitude DDD MM.MMMM	Heading (deg T)	Height (m)	Horizontal Distance (km) Between Positions	Horizontal Distance (km) Cumulative Total	% Slack	Cable Length (km) Between Positions	Cable Length (km) Cumulative Total	Comments
1	37 29.9400N	122 29.8623W		38		0.000			0.000	Building
			130.46		0.002		0.0	0.002		
2	37 29.9393N	122 29.8613W		38		0.002			0.002	
			219.21		0.007		0.0	0.007		
3	37 29.9363N	122 29.8643W		38		0.009			0.009	
			291.54		0.043		0.0	0.043		
4	37 29.9448N	122 29.8915W		38		0.052			0.052	
			304.36		0.025		0.0	0.025		
5	37 29.9523N	122 29.9052W		36		0.077			0.077	
			251.66		0.009		0.0	0.009		
6	37 29.9508N	122 29.9107W		36		0.085			0.085	
			317.72		0.014		0.0	0.014		
7	37 29.9563N	122 29.9171W		35		0.099			0.099	Hill Top
			353.97		0.005		0.0	0.005		
8	37 29.9589N	122 29.9174W		33		0.104			0.104	
			339.20		0.021		0.0	0.026		
9	37 29.9695N	122 29.9225W		18		0.125			0.130	
			326.89		0.009		0.0	0.009		
10	37 29.9734N	122 29.9257W		15		0.133			0.139	
			300.57		0.012		0.0	0.020		
11	37 29.9767N	122 29.9328W		11		0.145			0.159	
			274.48		0.020		0.0	0.021		
12	37 29.9775N	122 29.9461W		5		0.165			0.180	
			272.59		0.011		0.0	0.011		
13	37 29.9778N	122 29.9534W		4		0.176			0.190	Deadman
			289.90		0.021		0.0	0.021		
14	37 29.9817N	122 29.9670W		0		0.197			0.212	Waterline

Appendix C. Cable Information

ATOC Pioneer Seamount Cable Operations
Summary Information
Recovery and Deployment of cables

Bruce Howe

1 February 1996

Shore cable

Length	Line counters	5402 m,	TDR (55 µs)	5448 m
Loop resistance		9.48 Ω		

Point Sur cable

Recovered in two pieces.

East end length	LCE 12136 m,	TDR (123 µs)	12184 m
West end length	LCE 36816 m,	TDR (388 µs)	38435 m
Total length	LCE 48956 m,	TDR (511 µs)	50620 m
Position of break	36 17.732N 122 01.889W 108 m		
Spliced cable length		TDR (484 µs)	47945 m
Loop resistance	84.8 Ω		

The Point Sur cable had many cuts and gouges, maybe from contact with rocks on recovery. There were obvious wire rope marks near the break. The break was due to failure in tension as evidenced by the necked down steel wires. Approximately TDR 2675 m of bad cable were cut off from the recovered cable.

San Simeon cable

Length (TDR differs from deployment)		TDR (698 µs)	69144 m
Length recovered	LCE 47500 m,	TDR (486 µs)	48183 m
Loop resistance	83.5 Ω		
Remaining piece (San Simeon cable 1)		TDR (212 µs)	20960 m
1 35 38.115N 121 44.833W		Anchor South	
2 35 39.2 N 121 44.8 W		EOC	
3 35 51.43 N 121 46.10 W	970 m	EOC	
4 35 52.547N 121 46.258W	972 m	Anchor North	
Coordinates of 4436 m length of spare cable (San Simeon cable 2)			
1 35 31.467N 121 39.883W		EOC+Anchor West	
2 35 30.727N 121 37.407W		EOC East	
3 35 30.436N 121 36.481W		Anchor East	
Total length at San Simeon			25397 m

Pioneer Seamount

Shore section length	LCE 5502 m,	TDR (55 µs)	5428 m
Splice point	37 29.856N 122 33.145W 46 m		
Middle section length	LCE 42875 m,	TDR (433 µs)	42893 m
New Splice point	37 26.128N 123 00.794W 505 m		
Seaward section length	LCE 44812 m,	TDR (480 µs)	47509 m
Total length	LCE 93189 m,	TDR (968 µs)	95890 m

Insulation resistance (center to shield) was in all cases > 1 GΩ

TDR - Time delay reflectometer, uses 99.06 meters per microsecond
LCE - Linear cable engine counter
Compare with Summary of 7 January 1993, revised 5 May 1995

Appendix D. List of Personnel on M/V *Independence*

APL-UW

- Bruce Howe - Chief Scientist
- Steve Anderson
- Kate Bader
- Fred Karig
- Jim Mercer
- Le Olson

University of Michigan

- Kurt Metzger

SAIC/MariPro

- Randy Parker
- Dave Schieffen
- Billy Everson
- Robin Gauss
- Tom Elliott
- Randy Martinez
- Jim Hegeman
- Chris Hunt
- Cris Christianson
- Geoff Ball
- Bill McLennan
- Stephen Brown

Vector Cable Company

- Ben Donnell

Monterey Bay National Marine Sanctuary

- Aaron King

Mar Incorporated / M/V *Independence*

- Mark Wood - Master
- Tim Minniear
- Allan Ruiz
- Chris Waren
- Steve Cory
- Dave Ponce
- Harris Berger
- Josh Allen
- Kenny Lloyd

Appendix E. Point Sur Cable Route Coordinates

From: Point Sur East | To: Point Sur West

Posn No	Latitude DD MM.MMMM	Longitude DDD MM.MMMM	Heading (deg T)	Depth (m)	Horizontal Distance (km) Between Positions	Horizontal Distance (km) Cumulative Total	% Slack	Cable Length (km) Between Positions	Cable Length (km) Cumulative Total	Comments
1	36 21.7900N	121 58.6900W		126		0.000			0.000	REL_#2
			182.53		1.018		5.0	1.069		
2	36 21.2400N	121 58.7200W		120		1.018			1.069	EOC
			180.57		6.048		5.0	6.350		
3	36 17.9700N	121 58.7600W		92		7.066			7.419	
			273.60		2.940		5.0	3.087		
4	36 18.0700N	122 0.7200W		100		10.006			10.506	
			247.61		1.263		5.0	1.326		
5	36 17.8100N	122 1.5000W		108		11.269			11.832	
			286.39		0.655		5.0	0.688		
6	36 17.9100N	122 1.9200W		108		11.924			12.521	Break
			282.53		1.534		5.0	1.610		
7	36 18.0900N	122 2.9200W		130		13.458			14.131	
			269.65		3.114		5.0	3.274		
8	36 18.0800N	122 5.0000W		290		16.572			17.405	
			270.71		5.809		5.0	6.113		
9	36 18.1200N	122 8.8800W		678		22.380			23.517	
			250.55		1.778		5.0	1.870		
10	36 17.8000N	122 10.0000W		774		24.158			25.387	
			277.97		5.321		5.0	5.590		
11	36 18.2000N	122 13.5200W		931		29.479			30.977	
			239.99		8.696		5.0	9.134		
12	36 15.8500N	122 18.5500W		1174		38.175			40.111	
			269.99		2.771		5.0	2.909		
13	36 15.8500N	122 20.4000W		1208		40.946			43.020	
			317.21		1.764		5.0	1.852		
14	36 16.5500N	122 21.2000W		1227		42.710			44.872	
			360.00		1.202		5.0	1.262		
15	36 17.2000N	122 21.2000W		1210		43.912			46.135	
			55.54		3.970		5.0	4.185		
16	36 18.4150N	122 19.0140W		853		47.881			50.320	EOC
			10.99		1.532		5.0	1.609		
17	36 19.2280N	122 18.8190W		895		49.413			51.929	REL_#1

Appendix F. San Simeon Cable Route Coordinates

From: San Simeon South — To: San Simeon North

Posn No	Latitude DD MM.MMMM	Longitude DDD MM.MMMM	Heading (deg T)	Depth (m)	Horizontal Distance (km) Between Positions	Horizontal Distance (km) Cumulative Total	% Slack	Cable Length (km) Between Positions	Cable Length (km) Cumulative Total	Comments
1	35 25.8000N	121 21.0000W		548		0.000			0.000	ANCHOR
			288.01		1.973		5.0	2.072		
2	35 26.1300N	121 22.2400W		585		1.973			2.072	EOC
			290.20		28.639		5.0	30.074		
3	35 31.5000N	121 40.0000W		966		30.612			32.146	
			311.01		9.014		5.0	9.465		
4	35 34.7000N	121 44.5000W		1003		39.627			41.611	
			355.53		31.031		5.0	32.583		
5	35 51.4300N	121 46.1000W		970		70.658			74.194	EOC
			353.43		2.079		5.0	2.184		
6	35 52.5470N	121 46.2580W		972		72.737			76.377	ANCHOR

ATOC Spare Cable off San Simeon: Piece Left in Place October 1995

From: San Simeon 1 South — To: San Simeon 1 North

Posn No	Latitude DD MM.MMMM	Longitude DDD MM.MMMM	Heading (deg T)	Depth (m)	Horizontal Distance (km) Between Positions	Horizontal Distance (km) Cumulative Total	% Slack	Cable Length (km) Between Positions	Cable Length (km) Cumulative Total	Comments
1	35 38.1152N	121 44.8329W		992		0.000			0.000	ANCHOR
			1.42		2.007		5.0	2.107		
2	35 39.2000N	121 44.8000W		988		2.007			2.107	EOC
			355.04		22.701		5.0	23.836		
3	35 51.4300N	121 46.1000W		970		24.707			25.943	EOC
			353.43		2.079		5.0	2.184		
4	35 52.5470N	121 46.2580W		972		26.787			28.126	ANCHOR

ATOC Spare Cable off San Simeon: Short Piece Laid 2 November 1995

From: San Simeon 2 West — To: San Simeon 2 East

Posn No	Latitude DD MM.MMMM	Longitude DDD MM.MMMM	Heading (deg T)	Depth (m)	Horizontal Distance (km) Between Positions	Horizontal Distance (km) Cumulative Total	% Slack	Cable Length (km) Between Positions	Cable Length (km) Cumulative Total	Comments
1	35 31.4670N	121 39.8830W		964		0.000			0.000	EOC
			110.09		3.986		5.0	4.185		
2	35 30.7270N	121 37.4070W		923		3.986			4.185	EOC
			111.03		1.500		5.0	1.575		
3	35 30.4360N	121 36.4810W		905		5.485			5.760	ANCHOR

Appendix G. Signal Parameters

The parameters of the m-sequence signal associated with the ATOC Pioneer Seamount source are

source level	=	260 W (195 dB re 1 μPa at 1 m)
center frequency f_0	=	75 Hz
bandwidth	=	37.5 Hz
digit	=	2 cycles = 26.6667 ms
sequence length L	=	1023 digits
sequence period	=	27.2800 s
sequence law	=	2033 octal
sequence initialization	=	0000000001 binary
modulation angle	=	$\theta = atan(\sqrt{L}) = 88.209215°$
sequences sent	=	44 for 20-minute transmission (1200.32 s).

The *m*-sequence corresponding to the above parameters is

0000000001000001101101010000100111110010101010100000001110001000
0001011001111011101110101010110000010101011100001100011011000100
0100101010001000110101001010010010100000101110111110101101110100
0101110111111101100011001000111001000001001101100110001111110000
1010011110101011110001111000001100101011101001101110110010100110
1010110100010011101001001110000100001110111000101000011011110100
1111101010011100101000101011011001000011001110111100101110101111
0110110100000011110010011010001101110010010010000000011000010110
1111100011010000101111111111000000100100110000011101010001100110
0111111110100001111111001000101001011010011001101111110011001011
1110111101101111000011100110000111101100111001110001100000011010
0101011001001011000011010110101010010000100011110100011111100010
0100010000101011111001110101100110101111010111111011100110100111
0110100100011000100110010011110001011000111010000011111010010111
1001111101101011000101010011000101110011110011011011100000100010
110101110010110010110110110000000101000111011000010010111000111

If a 1 in the above sequence is equivalent to s = +1 and 0 to s = −1, then the signal sent is $cos(2\pi f_0 t + s(i(t))\theta)$, where $i(t)$ is the the digit number at time t.

Transmissions start 5 minutes plus one period (300 s + 27.2800 s = 327.2800 s) before the hour (UTC) at a level of 0.26 W (165 dB re 1 μPa at 1 m) and increase in level 6 dB every minute until the desired output level is reached. On a transmission day, transmissions will occur every 4 hours. The schedule will be adjusted to fit Marine Mammal Research Program requirements.

Appendix H. Engineering Test Transmissions

During the deployment of the ATOC Pioneer Seamount acoustic source, the following test signals were sent to verify correct operation of the source, as well as to elucidate results that differed from model predictions.

Signal A = m-sequence, ramp starts 5 minutes before the hour, 20 minute, 26 W (185 dB)
Signal B = m-sequence, ramp starts 5 minutes before the hour, 20 minute, 260 W (195 dB)

Local time clocks on the ship were shifted at midnight after the source was deployed because of daylight savings change.
Prior to 29 Oct, local = UTC - 7 hours, after 29 Oct, local = UTC - 8 hours.

Engineering Test transmissions

Local	UTC	
Sat 28 Oct 1917	Sun 29 Oct 302:0217	source touches down
at "hold" point about 400 m NE of source		
Sat 28 Oct 2200	Sun 29 Oct 302:0500	signal A
Sat 28 Oct 2300	Sun 29 Oct 302:0600	signal B
set local clocks back 1 hr at midnight during cable laying		
Sun 29 Oct 1000	Sun 29 Oct 302:1800	signal B
Sun 29 Oct 1100	Sun 29 Oct 302:1900	signal B
Sun 29 Oct 1200	Sun 29 Oct 302:2000	signal B
Sun 29 Oct 1300	Sun 29 Oct 302:2100	signal B
Sun 29 Oct 1400	Sun 29 Oct 302:2200	signal B, 40 minutes long
just after splicing the second length of cable to the first		
Wed 01 Nov 1400	Wed 01 Nov 305:2200	signal A, 5 minutes late
Wed 01 Nov 1500	Wed 01 Nov 305:2300	signal B
after final splice, from Pillar Point		
Thu 02 Nov 1200	Thu 02 Nov 306:2000	signal A
Thu 02 Nov 1300	Thu 02 Nov 306:2100	signal A
Thu 02 Nov 1400	Thu 02 Nov 306:2200	signal B

In summary, 12 transmissions were made: 4 were at 26 W and 8 were at 260 W, 11 were 20 minutes long and 1 was 40 minutes long. Total transmission time over the 4.8 days was 280 minutes (4.7 hours), a net duty cycle of 4%.

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13. ABSTRACT *(Maximum 200 words)*

The ATOC acoustic source was installed on Pioneer Seamount during October and November 1995. Three vessels were used for this work. On 5 October, M/V *McGaw* laid 3 nmi of cable at Pillar Point, California. The cable is terminated at the Pillar Point Air Force Station. On 14 October, a survey of the proposed source site on Pioneer Seamount was conducted using the U.S. Navy's Deep Submergence Vehicle *Sea Cliff* (DSV 4) deployed from M/V *Laney Chouest*. This survey determined the precise location for the source and deployed acoustic transponders for relocating the site. The source deployment using M/V *Independence* was done in four steps during 24 October to 3 November. One length of deep-stowed cable was recovered off Point Sur. The source was deployed on 28 October, and this first length of cable laid toward shore. A second piece of deep-stowed cable was recovered off San Simeon. It then was spliced to the first piece, laid to shore, and spliced to the cable at Pillar Point. Engineering test transmissions were made after deployment of the source to ensure that it was functioning correctly. The best estimate for the position of the center of the acoustic source is 37°20.5550′N, 123°26.7117′W at 938.7 m depth.

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